HORIZON Nxt®

Modular Infusion System

Service Manual

B. Braun
June 2000
950500 Rev E

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Manual Revision History

Table 1:

Date	Rev Letter	Description of Revision
1/97	A	Initial Release
5/98	B	Change company name to B. Braun
1/00	C	Change Battery Charging Reference
4/00	D	Tighten Solenoid Gap Tolerance
6/00	E	Add caution regarding electromagnetic field exposure

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1.0 INTRODUCTION

1.1 DISCLAIMER

Due to the criticality of product performance, B. Braun recommends that all required service on this product be performed only by an authorized B. Braun Service Center or a qualified biomedical repair professional who has attended the B. Braun service training course. Repairs should not be attempted without a current Service Manual. Repairs should not be attempted by other than qualified personnel that are knowledgeable in the areas of microprocessor controlled electronics, digital and analog circuitry, electromechanical devices, testing, static control and soldering techniques. Repairs should not be attempted which have not specifically been identified in this Service Manual.

WARNING: If the product is partially or completely disassembled, or a component or assembly has been replaced or repaired, the unit must undergo and pass all performance checks outlined in Section 3.6 of this manual and the appropriate calibrations and or tests outlined in Sections 3.7 and 3.8 prior to use for patient care. All final performance testing and calibration of the Horizon Nxt pump must be performed with a set that is acceptable for patient use with an exception for set sterility only. Failure to do so may cause bodily harm and will void all warranties and liabilities.

CAUTION: Rework of multi-layer boards should not be attempted unless personnel have attended and passed an accredited course in soldering techniques for this type of board and express written consent has been obtained from an authorized B. Braun Representative. Failure to do so will void all warranties.

CAUTION: Individual component replacement is not recommended and will void any and all warranties unless express written consent has been obtained from an authorized B. Braun Representative. B. Braun recommends board replacement as it may not be possible to test complete circuit function to factory specifications.

CAUTION: Do not use the pump in the presence of strong electromagnetic fields. The field may permanently damage the pump. For further information consult the manufacturer of the equipment in question.

By performing any repairs with or without use of this manual as reference, you hereby acknowledge and agree that B. Braun and its distributors shall be indemnified and held harmless from and against any and all damages, liabilities, actions or causes of action, including attorney's fees, directly or indirectly arising out of or resulting from such repairs.

You also understand that neither B. Braun nor its distributors shall be liable for any incidental or consequential loss, damage, or expense directly or indirectly arising from authorized or unauthorized repair of this device since the quality of repair, and the knowledge and experience of personnel performing repairs, as well as other factors relating to matters beyond B. Braun's control, directly affect the device and the results obtained from its use.

B. Braun neither assumes, nor authorizes any other person to assume for it, any other or additional liability or responsibility in connection with repair of this device. B. Braun accepts no financial obligations for any institution's authorized or unauthorized repair during the warranty period.

The information contained in this manual is current as of the date of issue.

1.2 WARRANTY

B. Braun hereby warrants that reasonable care has been used in the manufacture of each Horizon Nxt Infusion Pump. When properly used and maintained, it shall be free from defects in material and workmanship for a period of one year after the date of shipment. Any Horizon Nxt Infusion Pump that is found not to meet these standards within this one year period will be repaired after examination by B.Braun , or, at B. Braun's option, will be replaced without charge. If the defect has been caused by misuse, unauthorized modification, or abnormal conditions of operation, repairs will be billed at B.Braun's then current charges. In this case, an estimate will be submitted before work is started, if requested. The defective device should be returned to B. Braun properly packaged, postage prepaid. Loss or damage in return shipment to B. Braun will be at the purchaser's risk. The foregoing express warranty, as conditioned and limited, is in lieu of and excludes all other warranties not expressly set forth herein, whether expressed or implied by operation of law or otherwise including, but not limited to, any implied warranties of merchantability or fitness, since handling, storage, and cleaning of these devices, as well as factors relating to other matters beyond B. Braun's control, directly affect these devices and the results obtained from their use. B. Braun shall not be liable for any incidental or consequential loss, damage or expense, directly or indirectly arising from the use of this device other than replacement of all or part of it. B. Braun neither assumes, nor authorizes any other person to assume for it, another or additional liability or responsibility in connection with this device. This warranty will not apply to any Horizon Nxt Infusion Pump or component thereof which has been:

- Repaired by anyone other than authorized B. Braun trained technician or repair facility;
- Altered in any way that, in B. Braun's judgement, affects its stability or reliability;
- Subjected to misuse, negligent handling, or accident;
- Used in any manner not according to the instructions furnished by B. Braun in the Operation Manual and/or Service Manual.

This warranty extends only to the first purchaser or lessee and does not extend to, and may not be enforced by, any other person.

1.3 INTENDED USE

This manual is intended to be used by a qualified biomedical service professional for the troubleshooting and repair of the referenced equipment. Repair of the device should only be performed by a qualified biomedical service professional. Although it is not mandatory that each service professional be certified by B. Braun prior to servicing the Horizon Nxt Pump, it is recommended, and will be made available to your institution upon the expiration of the standard Horizon Nxt Infusion Pump warranty. Please contact Customer Service (see Chapter 9) for additional information on the training classes and fee structure. B. Braun maintains the right to withhold the purchase of parts until a service professional has been certified by B. Braun.

NOTE: This manual contains information and data proprietary to B. Braun This information is provided solely for technical personnel in maintaining and servicing the Horizon Nxt Infusion Pump. None of the information contained herein may be duplicated or used in any manner other than for the maintenance and servicing of the pumps or their component parts. Any unauthorized use of the information contained herein may subject the user to substantial liability for infringement of trade secrets, copyright, and patents.

This Service Manual is organized into ten chapters as outlined in the Table of Contents. A Horizon Nxt Operation Manual is included at the end of this manual for easy reference. Please refer to Chapter 1 of the Operation Manual for the intended use of this infusion pump.

2.0 DESCRIPTION

2.1 VISUAL INDICATORS AND CONTROLS

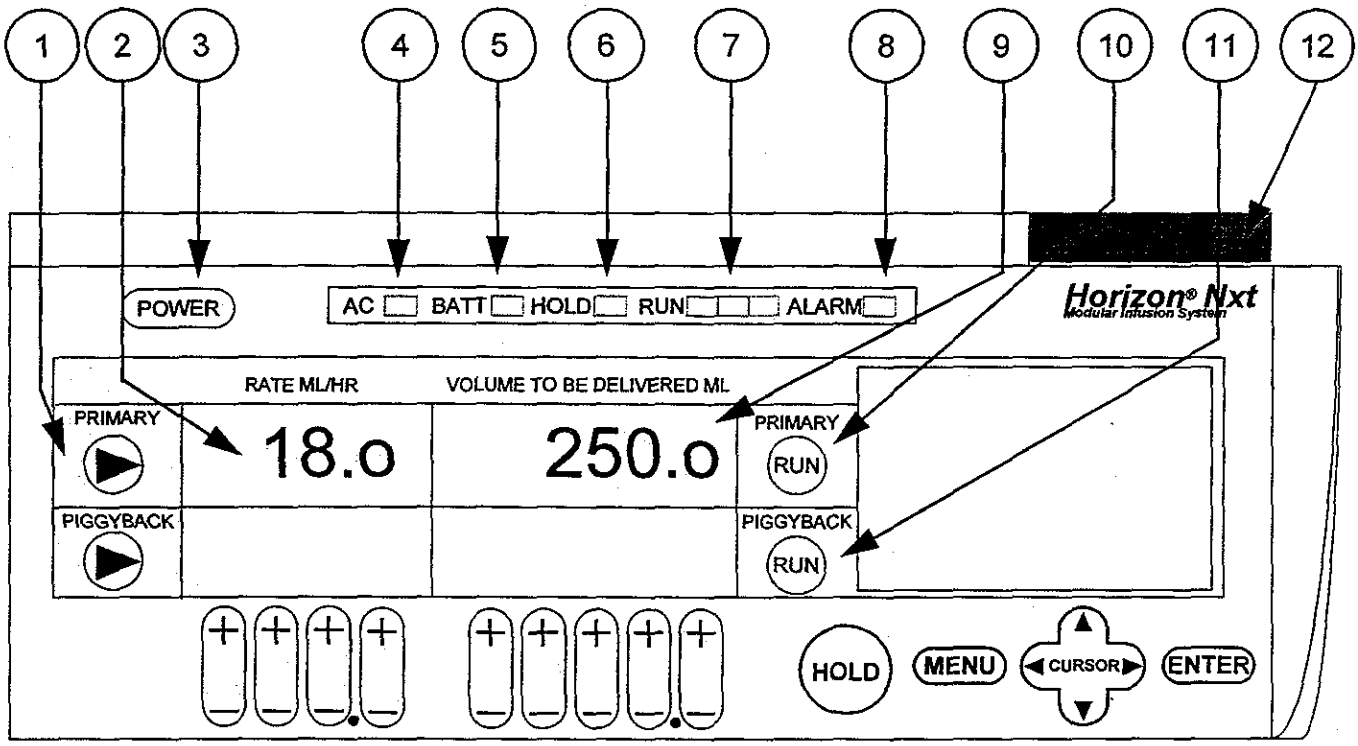
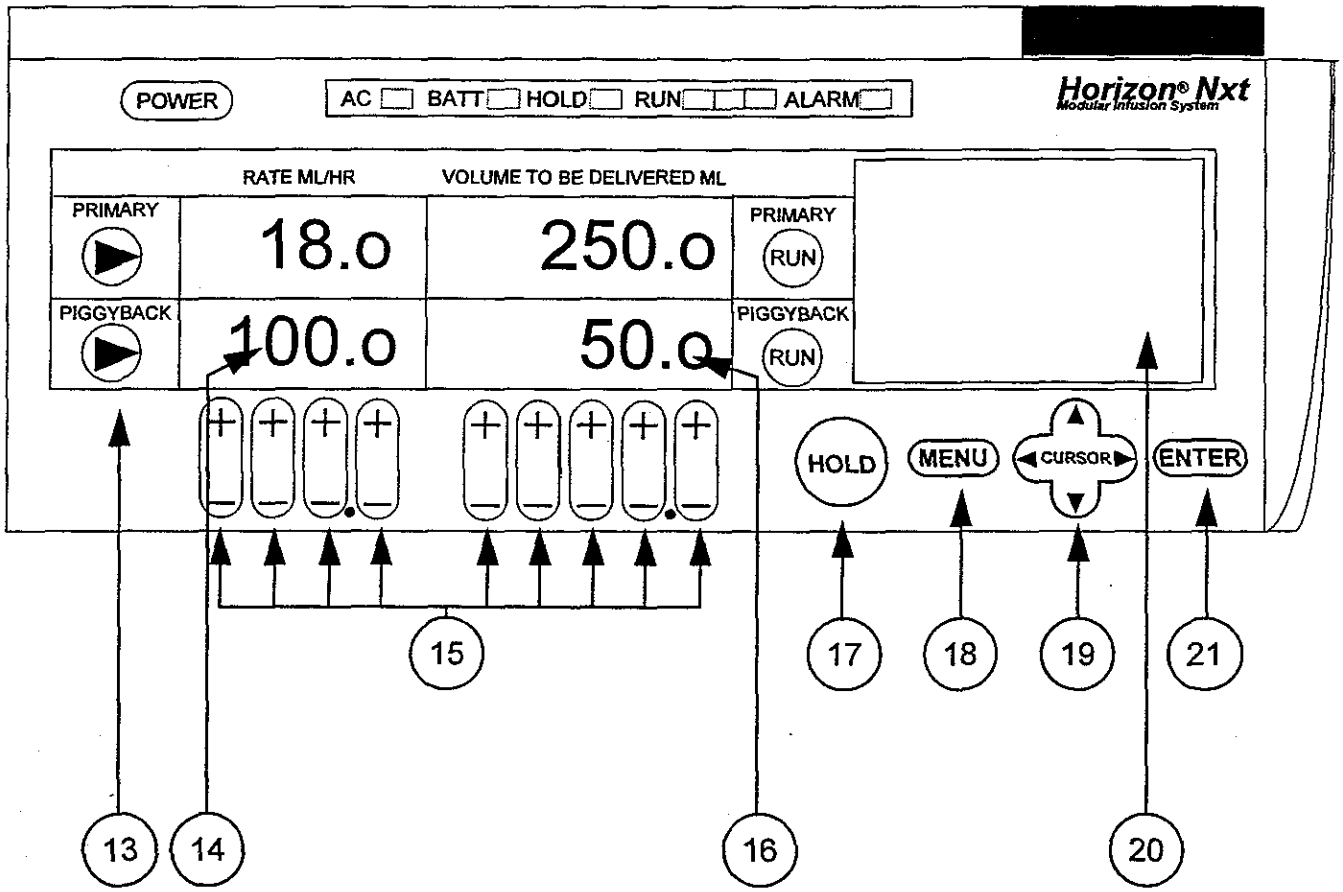


Figure 2-1: Front View

1. PRIMARY Indicator Key	7. RUN Indicator
2. Primary Rate Display	8. ALARM Indicator
3. POWER Key	9. Primary Volume Display
4. AC Use Indicator	10. PRIMARY RUN Key
5. Battery Use Indicator	11. PIGGYBACK RUN Key
6. HOLD Indicator	12. Door Lever

Figure 2-2: Front View (Cont'd.)



13. PIGGYBACK Indicator Key	18. MENU Key
14. Piggyback Rate Display	19. CURSOR Keys
15. Data Keys	20. Information (LCD) Display
16. Piggyback Volume Display	21. ENTER Key
17. HOLD Key	

Figure 2-3: Right View

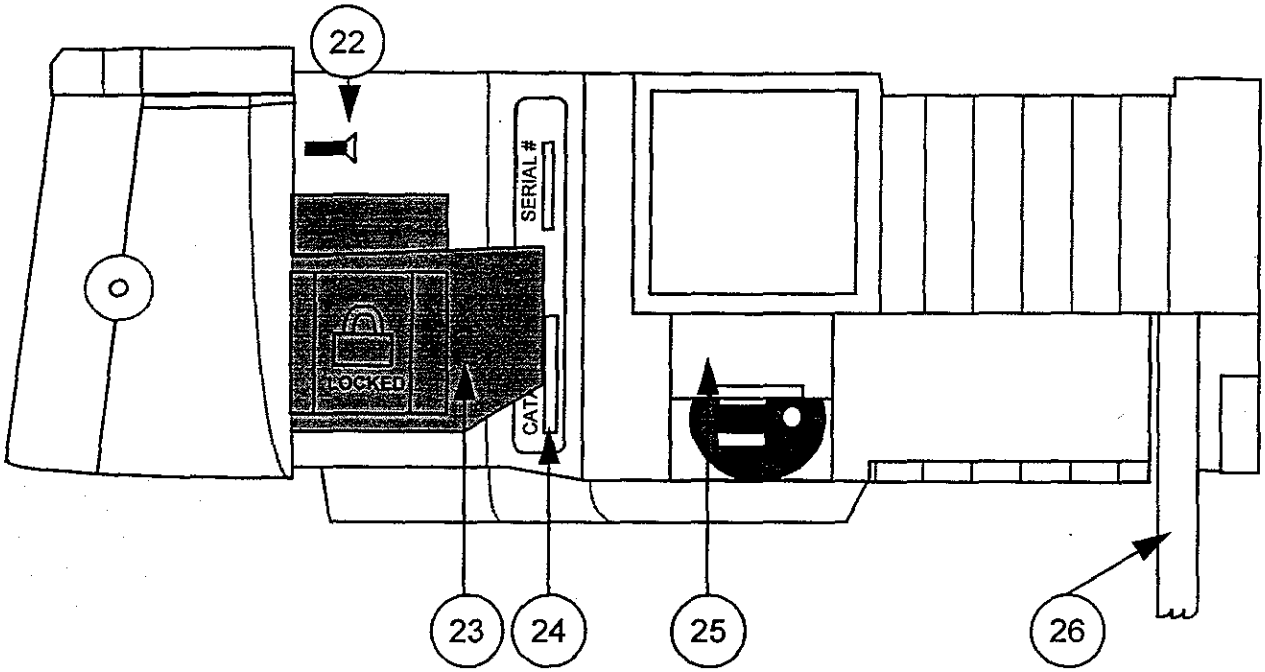
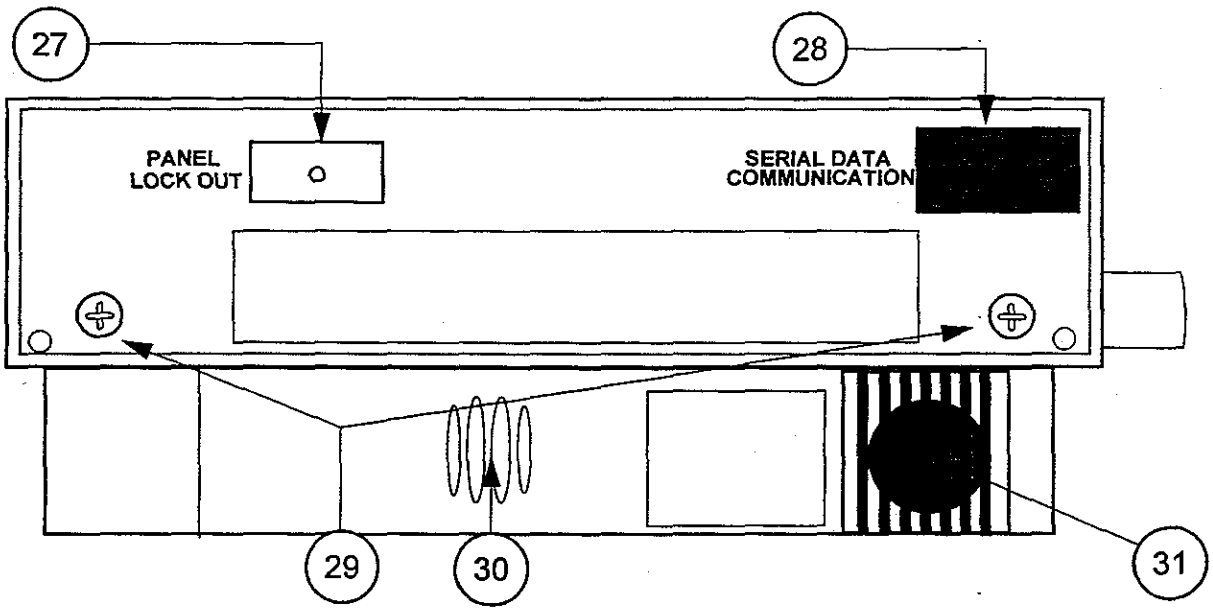
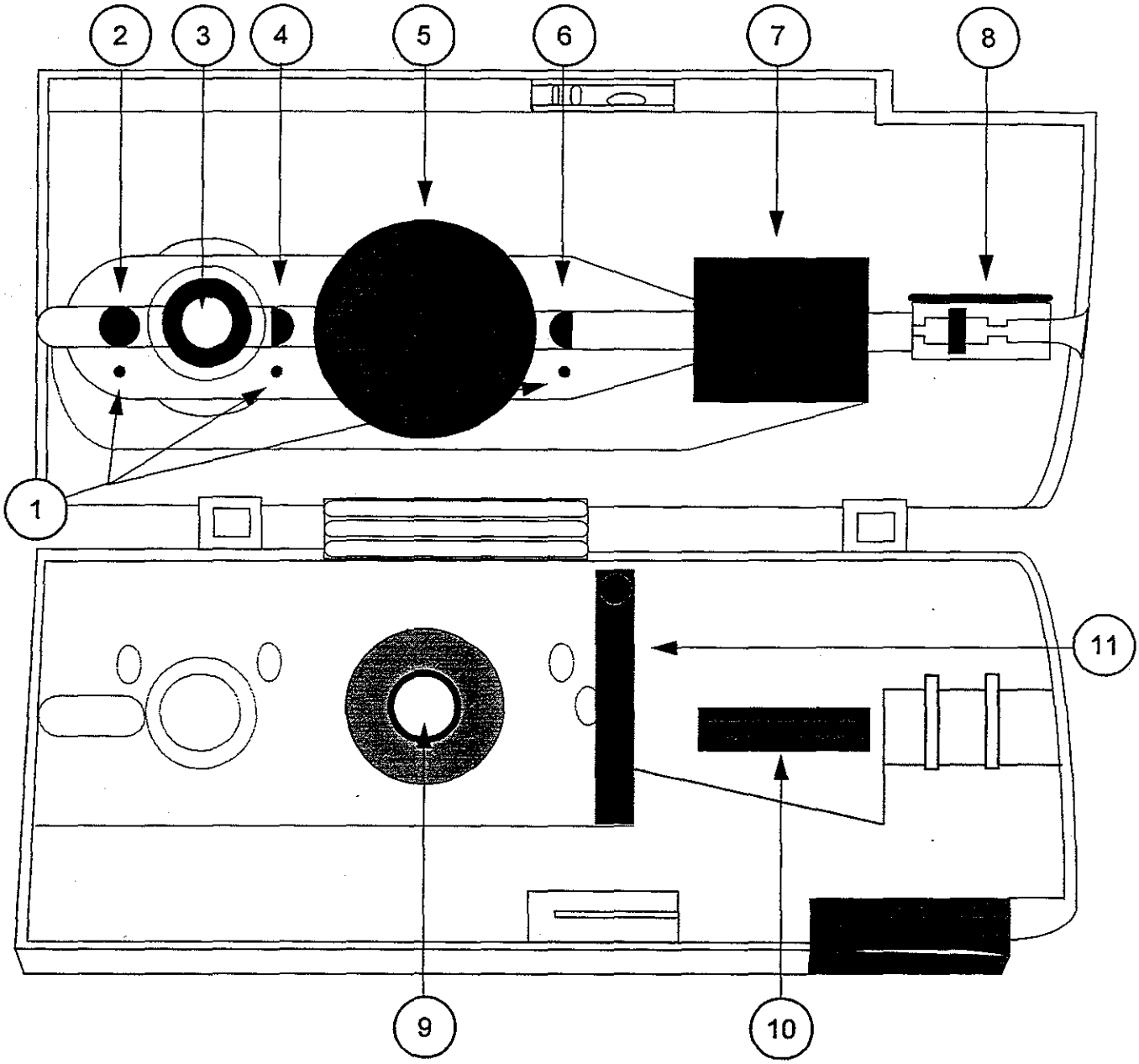


Figure 2-4: Rear View



22. Phillips Head Case Top Screw	27. PANEL LOCK OUT Switch
23. Pole Clamp	28. SERIAL DATA COMMUNICATIONPort
24. Catalog and S/N Identification	29. Quarter-turn Case Top Screws
25. Daisy Chain Outlet Door	30. Piezo Alarm Speaker (Model 610-012)
26. AC Power Cord	31. Main Speaker

Figure 2-5: Front View, Door Open



1. Cassette Alignment Pins	7. Air-In-Line Detector
2. Inlet Valve	8. Anti-Freeflow Socket
3. Refill Piston	9. Pressure Transducer
4. Transfer Valve	10. Tube Pusher
5. Petal Module Cover	11. Spring (Free Flow Prevention)
6. Restriction/Outlet Valve	

2.2 SPECIFICATIONS

Mechanism:	Volumetric (Non Drop-Counting), Positive Pressure Displacement Reservoir
Dimensions:	Width 12.4" (31.5 cm) Height 4.8" (12.2 cm) Depth 12.2" (31.0 cm)
Weight:	Approximately 11.9 lbs (5.4 kg)
Power Requirements:	90-132 VAC, 30 Watts, 47/63 Hz excluding accessories (domestic), 180-264 VAC, 30 Watts, 47/63 Hz excluding accessories (international)
Grounding Resistance:	Meets UL Standard 544
Leakage Current:	Meets or exceeds UL Standard 544, Section 27.2, and ANSI/AAMI Safe Current Limits (July 9, 1985) for each device.
Plug:	Hospital Grade (3 pin)
Pole Size Range:	0.75" to 1.25"
Battery:	12 Volt sealed lead-acid battery for ambulatory use. Run time is dependent on the state of battery charge and the rate of fluid delivery.
Rate Range:	Standard: (Primary and Piggyback) 0.1 to 999.9 ml/hr Micro: (Primary and Piggyback) 0.1 to 99.9 ml/hr
Keep Open Rate:	3 ml/hr for prescribed delivery rates of 3 to 999.9 ml/hr, or the continuation of the prescribed delivery rate for 0.1 to 2.9 ml/hr settings
Volume to be Infused:	0.1 to 9999.9 ml
Fluid Types:	All standard I.V. fluids, including lipids & TPN
Occlusion Pressure:	75, 100, 200, 300, 400, 500 and 750 mmHg. Standard Mode default is 300 mmHg. Micro Mode default is 100 mmHg. Both defaults are user adjustable.
Alarms:	Air-In-Line, Battery Very Low, Container Empty, Door Open, Downstream Occlusion, Hold Time Exceeded, Repair Instrument, Set Improperly Loaded, Set Piggyback Rate, Set Piggyback Volume, Set Primary Rate, Set Primary Volume, System Alarm, Solution Alarm
Air-In-Line Alarm:	0.09 cc

Hold Time Exceeded:	Activated after three minutes without user interaction (deactivated if the door of the pump is open)
Memory:	Permanent data retention after the pump is turned off, unless the Data Retention Defaults have been otherwise selected in the Biomed Options.

3.0 RECOMMENDED RECEIVING PROCEDURE

3.1 RECEIVING NOTICES

New Device Notice: Any new device that does not meet factory specifications during in-coming inspection will be replaced only if the device is not altered, i.e. hospital identification markings, asset control numbers, or preventative maintenance tags. If a device is used on a patient, it will not be considered an out of box failure.

WARNING: If the product is partially or completely disassembled, or a component or assembly has been replaced or repaired, the unit must undergo and pass all performance checks outlined in Section 3.6 of this manual and the appropriate calibrations and/or tests outlined in Sections 3.7 and 3.8 prior to use for patient care. All final performance testing and calibration of the Horizon Nxt must be performed with a set that is acceptable for patient use with an exception for set sterility only. Failure to do so may cause bodily harm and will void all warranties.

3.1.1 Damaged Goods

Upon receipt, count and inspect your freight before the carrier departs. Damaged merchandise should not be accepted. Identify any items that are damaged or lost, and have the extent of the damage or loss noted on the customer's copy of the delivery document by an agent of the transportation company. If damage is discovered after receipt of shipment, notify the transportation company immediately, and request that inspection be made and an inspection report rendered. B. Braun will be happy to issue a credit for the loss or damage, and file a claim with the carrier, providing your reque and the carrier's freight bill indicating the item and quantity damaged or not received are promptly forwarded to the Carrollton, Texas office (see Chapter 9), and received within ten days. The claim request must be accompanied by a delivery receipt or an inspection report upon which the transportation company has properly noted such damage or loss.

3.1.2 Goods Received in Error

Items ordered or shipped in error may be returned to the warehouse provided Customer Service is notified (see Chapter 9), and the products are returned within 14 days. Items ordered in error must be returned freight prepaid by the customer.

Credit will be issued for all returns for goods received in error provided:

1. Proper authorization has been obtained (see Chapter 9).
2. Products are in the original undamaged cases, suitable for immediate resale.
3. Products are current inventory items.
4. Merchandise has been shipped and billed to the customer by B. Braun.

Certain products are not eligible for return for credit. These are:

1. Products which have been used.
2. Products whose labels or seals have been tampered with or removed.

Except in the case of a B. Braun error, items must be returned freight prepaid by the customer.

3.1.3 Late Shipments

B. Braun shall be excused from any delay in, or impossibility of performance due to any cause beyond its or its suppliers' or subcontractors' control, including, but not limited to: acts of God, war, acts of government, acts of purchase priorities or allocations, raw material shortages, fire, flood, strike, labor trouble, sabotage or delay in obtaining labor, materials, equipment, or transportation.

3.1.4 Expedited Shipments

When expedited transportation, specialized services, or alternate transportation modes are specified by the customer, an additional charge to cover the premium expense will be added to the invoice.

3.1.5 Receiving Inspection

Each Horizon Nxt Infusion Pump is factory inspected and tested prior to its final packaging and shipment. There is, however, the possibility of in-transit damage which may or may not be obvious; therefore, the following inspection is recommended. If functional testing is required upon receipt by your (customer) policy, refer to the section in this chapter titled "CHECK-IN PROCEDURE."

1. Before opening the shipping container, inspect it carefully to assure the absence of obvious damage. If damage is present, notify the freight carrier immediately, and wait to open the container until a representative of the shipping company is present. (It is difficult to place responsibility for shipping damage after the shipping container is opened). Do not return damaged equipment to the manufacturer unless specifically authorized to do so by the company, whether or not the company is responsible for the repair.
2. Remove the pump from the shipping carton.
3. Carefully inspect the pump for dents, scratches, missing parts, or any other obvious signs of shipping damage.
4. Make sure the door of the pump opens and closes easily, without binding, and that it is properly aligned with the bezel.
5. Make sure there are no visible dents, tears or scratches on the pump membrane panel.
6. Check the Pole Clamp for ease of operation.
7. Inspect the power cord for nicks or cuts, and the plug for bent or insecure prongs.
8. Make sure the petal module cover, valve tips and pressure transducer cover are not torn or otherwise damaged.

3.2 CHECK-IN PROCEDURE

Prior to use, it is recommended that the pump be checked-in according to Sections 3.3 through 3.8 of this manual. If the pump fails to operate, contact B. Braun for a Returned Materials Authorization Number (RMA#). See Chapter 9 for information on contacting the company.

Each pump has been inspected and tested prior to shipment; however, in-transit handling or repair work may have caused some misalignment. Therefore, the procedures outlined in this chapter are intended to be used by qualified service personnel in the initial and routine checks of the Horizon Nxt Infusion Pump.

3.3 MECHANICAL INSPECTION

3.3.1 Door Alignment Inspection

1. Make sure the door of the pump opens and closes easily, without binding, and that it is properly aligned with the bezel. The door latch allows the door to close completely.
2. The gap on each side and along the top of the door is symmetrical.

3.3.2 Pole Clamp Inspection

See Table 3-2, # 1.

3.3.3 Switch Inspection

See Table 3-2, # 2.

3.3.4 Gasket and Hardware Inspection

1. All gaskets and seals are securely attached.
2. Petal module cover and valve tips are in place and in good condition.
3. The cover on the pressure transducer shall not have any rips, tears, punctures or indentation marks.
4. All screws are tight and secure.
5. No cracks are present in the bezel or inner door face.
6. Tube pusher is intact and securely mounted.
7. No cracks in the case or handle exist.
8. Inspect the power cord for nicks or cuts. Inspect the plug for bent or insecure prongs.

3.4 MAIN BATTERY CHECK AND CHARGING

All rechargeable batteries automatically discharge when not in use. The rechargeable battery used in this pump is no exception. Therefore, it is suggested that before attempting to use the pump for the first time, the battery be fully charged by connecting the power cord of the pump to a hospital grade electrical outlet. Allow at least 24 hours to fully charge the battery from a fully discharged condition. In order to maintain the battery in a fully charged condition, the pump should be plugged into a hospital grade electrical outlet whenever possible. When charging multiple devices in a storage facility, ***not in the vicinity of patients***, 12 Horizon® and/or Horizon Nxts may be Daisy Chained together for outlet conservation purposes.

3.5 DEFAULT SOFTWARE SETTINGS

1. Set all defaults according to your individual institution's needs. Use PC Docking to program the pumps. Refer to the PC Docking Operation Manual, Part No. 950441, for instructions.
2. Verify that the pump's calendar and clock are set appropriately.

A list of all the options in the Menu System, and the submenus in which they can be placed, is available by contacting Technical Support Services at (800) 627-7867.

3.6 SIMULATED USE AND PERFORMANCE CHECK

Equipment Required:

1. Horizon® Pump I.V. Set
2. Container with suitable fluid in it
3. Needle and 3ml Syringe
4. I.V. pole or equivalent
5. AC power source

3.6.1 Test Procedure: Simulated Use

Table 3-2: Simulated Use Initial Checkout

Action	Observation
1. Unlock the Pole Clamp by rotating the Pole Clamp lever clockwise toward the front of the pump 1/4 turn. Attach the pump to an I.V. pole by pressing down on the unlocked Pole Clamp lever. While holding the lever down, position the pump such that the pole is seated in the V-block of the instrument case. Release the Pole Clamp. With the pump now supported by the I.V. pole, use one hand to lightly press down on the pump. Rotate the Pole Clamp lever 1/4 turn counterclockwise towards the back of the pump to lock the Pole Clamp.	1. Verify the Pole Clamp mechanism tightens firmly onto the pole. **Note:** As the open Pole Clamp lever is snugged tighter, the pump will become more securely mounted on the I.V. pole.
2. Press the Power Key to turn on the pump.	2. The speaker will sound a tone. The BATT and HOLD LEDs will illuminate. The Rate and Volume To Be Delivered columns will display values, the LCD will illuminate and display: Load the Set and then close the Door. Total Infused = 0.0 ml Occlusion Limit = 300 mmHg **Note:** If no keys have been pressed for approximately 30 seconds, "HOLd" will be displayed in the Primary or Piggyback channel, whichever is not active. If no keys have been pressed for 3 min., "HOLd" will flash in the Primary Volume To Be Delivered column of the LED's and the alarm will sound.

Table 3-2: Simulated Use Initial Checkout

3. Individually press and hold the + and - portion of each DATA Key to verify operation. Press the PIGGYBACK INDICATOR Key and repeat. Return the Piggyback Rate and Volume To Be Delivered values to zero.	3. Key clicks are heard as the LEDs sequence. An audible tone will sound as the hundreds column of the Rate and the thousands column of the Volume To Be Delivered are advanced past 9 or if any column is decremented past 0. This same tone will sound if an attempt is made to set the rate or volume less than 0.o ml. **Note:** Whichever key is depressed, PRIMARY INDICATOR or PIGGYBACK INDICATOR, the respective display will illuminate brighter, while the other display becomes dimmer.
4. Enter a Primary rate of 900 and a Primary volume of 10. Press the PRIMARY RUN Key.	4. The audible alarm will begin to sound and repeat approximately once every three seconds. The ALARM LED will illuminate. The LEDs in the Primary Volume To Be Delivered column will flash "SEE HELP". The LCD will display: CLOSE ROLLER CLAMP Then open door. Check Placement of Secure Flow Clamp ↓ ...(picture)...
5. Press the MENU Key, then the HOLD Key.	5. The LCD will display: Load the Set and then close the Door. Total Infused = 0.o ml Occlusion Limit = 300 mmHg Flow Clamp Position HELP
6. Press the MENU Key followed by the down arrow CURSOR Key until "Alternate Menu" is highlighted. Press the ENTER Key. Press the down arrow CURSOR Key until "Set LCD Contrast" is highlighted. Press the ENTER Key.	6. The LCD will display: EXIT Adjust cursor ← → until this message is clear. Then press Enter key.
7. Cursor left and right.	7. The contrast changes from high to low and back to high again. The backlight intensity should be present and not erratic or flickering.

Table 3-2: Simulated Use Initial Checkout

8. Press the ENTER Key.	8. The LCD will display: Load the Set and then close the Door. Total Infused = 0.o ml Occlusion Limit = 300 mmHg Flow Clamp Position HELP
9. Open the door.	9.The only display change will occur after several seconds, after which the PIGGYBACK LEDs will display "HOLd". Opening the door disables the Hold Time Exceeded alarm.
10. Spike the fluid container with the I.V. set, and prime the set with fluid. Make sure all air is removed from the set before closing the roller clamp. Load the cassette into the pump mechanism according to the instruction label inside the door. Close the door.	10.The Rate and Volume To Be Delivered columns will display those values that were present prior to opening the door. The LCD will illuminate and display: Set the Rate & Volume. Then Press RUN. Total Infused = 0.o ml Occlusion Limit = 300 mmHg Flow Clamp Position HELP
11.Press the PIGGYBACK Indicator Key and enter a Piggyback rate and volume of 0.o.	11. The LCD will drop the last line of text. The row of PIGGYBACK LEDs will illuminate. The row of PRIMARY LEDs will become dim.
12.Close the clamp downstream from the cassette and press the PRIMARY RUN Key.	12. The "Total Infused =" value should stop increasing with a complete occlusion and an audible alarm should sound associated with a flashing LED message of "OCCL." **Note:** The amount of time will vary depending upon how far downstream the clamp is, the occlusion limit setting as well as the infusion rate. **Note:** The Occlusion Limit will automatically increase to 400 mmHg to compensate for the effect of tubing flow resistance as infusion rates exceed 399.9 ml/hr.
13. Press the HOLD Key and open the downstream clamp. Clamp the tubing upstream of the pump and press the PRIMARY RUN Key.	13. The "Total Infused =" value should stop increasing with a complete occlusion and an audible alarm should sound associated with a flashing LED message of "SOLU." **Note:** The amount of time will vary depending upon how far upstream the clamp is, the occlusion limit setting as well as the infusion rate.

Table 3-2: Simulated Use Initial Checkout

14. Press the HOLD Key and unclamp the upstream tubing. Inject an air bubble of at least 0.9 ml into the "Y" site of the tubing on the upstream side of the pump. Press the PRIMARY RUN Key.	14. The cassette chambers will be filled and pressurized. The HOLD LED will extinguish. The RUN LEDs will begin to illuminate sequentially. The LCD will display: Time Left = 0 hr 0 min Total Infused = 1.8 ml Occlusion Limit = 400 mmHg
15. When the air bubble reaches the pump, tilt the pump such that the distal (delivery end) is pointing upwards, toward the ceiling.	15. The alarm will sound as the air bubble passes into the air-in-line detector. The ALARM LED will illuminate. The RUN LEDs will extinguish. The LEDs in the Volume To Be Delivered column will flash "Air." The LCD will display: Air In Line To Silence Alarm Press MENU for help, or Press HOLD.
16. Press the MENU Key.	16. The alarm will silence. The ALARM LED will extinguish. The HOLD LED will illuminate. The LCD will display: - Air in downstream tubing - Tubing improperly inserted in Air-In-Line Detector. Press HOLD or Press RUN
17. Open the door and flush the air in the tubing. Perform the Volumetric Test as described in Section 3.7.1. Enter a Primary Volume to be Delivered of 10.0 ml. Press the RUN Key.	17. At the end of infusion, the pump will go into Keep Vein Open mode.

Table 3-2: Simulated Use Initial Checkout

18. Wait until the infusion is complete.	18. An alarm sounds, indicating a KVO state of operation. The primary rate will be 3.o ml/hr and the volume to be delivered will be 0.o, each will be flashing. The LCD will display: KVO: PRIMARY COMPLETE Total Infused = 10.o ml Occlusion Limit = 300 mmHg
19. Open the door.	19. The alarm will sound. The Alarm LED will illuminate. The LEDs in the Volume to be Delivered column will flash "door."
20. Press the HOLD Key.	20. The alarm will silence. The HOLD LED will illuminate. The Primary rate will display 900 and a Volume to be Delivered of 0.o. The LCD will display; PRIMARY COMPLETE Time Left = 0 hr 0 min Total Infused = 10.o ml Occlusion Limit = 300 mmHg
21. Press the MENU Key. Press the ENTER Key to "Clear Total Infused."	21. The LCD will display: The present Total Infused of 10.oo ml will be zeroed. Is this OK? YES NO
22. Press the ENTER Key.	22. The LCD will display: PRIMARY COMPLETE Time Left = 0 hr 0 min Total Infused = 0.o ml Occlusion Limit = 300 mmHg
23. Press the POWER Key to turn the pump off.	23. The LED's in the Volume to be delivered column will display "----" until the device has completed the power down cycle. The AC LED will remain lit while the pump is plugged into an AC power supply.

3.7 VOLUME DELIVERY ACCURACY

Equipment Required:

1. Distilled water in an I.V. fluid container
2. Horizon® Pump I.V. Set
3. Electronic Balance or Precision Collection Vessel
4. Needle or dispenser tip with a Luer lock type connector.

3.7.1 Test Procedure: Volumetric

1. Connect the fluid delivery set to the fluid container.
2. Attach the needle to the delivery end of the I.V. Set.
3. Completely prime the set with fluid so all the air is expelled from the set, and then close the roller clamp on the set.
4. Insert the cassette into the pump according to the instructions inside the door of the Horizon Nxt pump.
5. Close the door and press the POWER Key to turn on the pump.
6. Open all clamps and enter:

Table 3-3: Volumetric Test Values

Volume	Rate	Pressure	Acceptable Limit
10 ml	120 ml/hr	300 mmHg	9.5 - 10.5 ml

7. Place the collection vessel on the balance, zero the reading, and suspend the needle over the collection vessel.
8. Press the RUN Key.
9. When the pump goes into the Keep Vein Open mode, press the HOLD Key immediately. Make sure the actual volume delivered is between the acceptable limits listed in the above table.

Note: 1 ml = 1 cc = 1 g of distilled water at room temperature (70° F)

10. Zero the reading on the balance. If the actual values are not within the specifications, test the pump with additional I.V. fluid delivery sets. If the values remain outside the specifications, return the pump to an authorized B. Braun Service Center.

Note: If using other accuracy test methods, in addition to the above, be sure to compensate for the adaptive energy processing used to conserve battery power and reduce noise as described in section 5.5.7.2 "Motor Controllers." This dynamic processing of resistance to flow will cause the motor energy to rise and fall at the beginning of an infusion (each time the pump transitions from the Hold state to the Run state). This results in several (varies with the system dynamics and rate) momentary pauses of the motor as the energy is changed during the first few delivery cycles after the RUN Key is pressed. Manufacturers of biomedical test equipment will supply you with written instructions for use of their equipment when testing I.V. pumps which employ this type of energy processing. While volumetric analyzers ar different, typically all that is required is that you allow 5-10 milliliters of fluid to bleed fro

the system prior to starting the timer(s) or counter(s). A 3-way stopcock is very useful here. Contact the manufacturer of you volumetric analyzer to ensure proper software and testing procedures are used.

3.8 ELECTRICAL SAFETY CHECK

Equipment Required:

1. Medical equipment electrical safety analyzer
2. AC power source

3.8.1 Test Procedure: Electrical

1. Plug the analyzer into an AC outlet.
2. Make sure the analyzer is functioning properly, according to your institution's protocol.
3. Plug the pump into the AC outlet of the analyzer.
4. Attach the probe to a single lead and touch it to the aluminum plate which supports the Daisy Chain outlet on the side of the pump or any protruding metal component.

Note: If using a manual probe for your resistance checks, you will need to make contact with either the metal frame of the power supply, located next to the Daisy Chain outlet, or the stainless steel door latch. Being stainless steel, the door latch makes for a difficult contact; you may need to scratch and scrape the probe on the latch.

5. Set the grounding selection to "No Ground."
6. Set the polarity to "Normal."
7. Press the POWER Key to turn on the pump.
8. Press the Chassis Leakage button and make sure the reading does not exceed the UL 544 or the IEC 601-1 specifications as indicated below.

Note: As of the date this manual was written, the AC leakage current specifications for both UL 544 and IEC 601-1 is 100 microamps for patient vicinity equipment. When using the Daisy Chain feature on the Horizon Nxt (plugging one Horizon or Horizon Nxt into another), the chassis leakage current is cumulative. Therefore, test all units connected as one system. The number of pumps interconnected at any time should not exceed the 100 microamp limit.

9. Set the polarity to "Reverse."
10. Press the Chassis Leakage button again. Make sure the reading does not exceed the UL 544 or the IEC 601-1 specifications.
11. Press the HOLD Key.
12. Set the polarity to "Off."
13. Set the grounding selection switch to "Ground."
14. Press the Ground Wire Resistance button. Make sure the reading does not exceed the UL 544 or the IEC 601-1 specification.

Note: As of the date this manual was written, the ground wire resistance specification for a device with a non-detachable power cord for UL 544 and IEC 601-1 is 200 milliohms.

15. Press the POWER Key on the pump.
16. Repeat steps 8 - 14, skipping step 11, with the power off (optional).
17. Disconnect the pump from the analyzer. Disconnect the analyzer from the AC power source.

4.0 THEORY OF OPERATION, GENERAL DESCRIPTION

The following describes the basic theory of operation for the Horizon Nxt pump. The organization of the material follows a general to specific format. The first section, Section 4.1, gives an overall description of a few significant design features. The next section, Section 4.2, is intended to give the reader a top level functional description. The detailed descriptions have been placed in Chapter 5 for clarity. Related schematics and drawings are cross-referenced where applicable. Appendix A lists the common abbreviations and symbols used throughout this chapter.

4.1 GENERAL DESIGN FEATURES

4.1.1 Patient Safety

Patient safety was a primary concern in the development of the Horizon Nxt pump. The operation of the Horizon Nxt pump incorporates a product design with features that optimize the safety of prescribed infusions.

Alarm and troubleshooting information are clearly visible, easy to read, and provide specific directions to correct problems as well as a list of possible causes.

The **Alarm Log and Operations Log** use the Horizon Nxt's real time clock to record up to 255 separate events to assist in troubleshooting problems and documenting a specific series of events.

Automatic dose rate calculations are performed by Horizon Nxt's unique Dose Mode. Nursing convenience and dosing accuracy are enhanced by both this feature and the Drug Menus.

The Horizon Nxt's **ease of use** is one of the strongest factors contributing to patient safety. The method of operation is easy to learn. A wide variety of information provided by the data and information displays assist the user at each step of the infusion process.

Full visibility of operating parameters is accomplished with the LED data displays and the LCD information display.

Reduced cord clutter around the bed-side results from using the Horizon Nxt's Daisy Chain approach to power cord management. Multiple pumps can be Daisy Chained together, only one of which needs to be plugged into the wall.

The Horizon Nxt's **Anti-Freeflow mechanism** provides protection against inadvertent free flow when the Horizon® Pump I.V. Set is removed from the pump.

Tamperproofing of the user selected operating parameters is provided in two levels. Rate changes during operation require the operator to validate the change by pressing the ENTER Key within six seconds. Complete lock out of the front panel is available by pressing the PANEL LOCK OUT Key on the back of the pump.

User selectable variable occlusion pressure limits of 75 (approximately equal to gravity with fluid at 3.4 feet above the I.V. site), 100, 200, 300, 400, 500 and 750 mmHg settings allow the maximum occlusion pressure to be tailored to each patient's specific needs.

The innovative **Pole Clamp** design provides rapid and secure attachment to a variety of standard poles. While supporting the pump with both hands, the pump is attached to the pole, giving the u greater control of this process.

4.1.2 Ease of Operation and Repair

Ease of operation is enhanced by characteristics or features such as the Pole Clamp, stackability of pumps, Daisy Chaining of power cords, and a full array of displays that provide for optimal interaction between the pump and the user.

Ease of repair is facilitated through a modular approach to instrument design, assembly and disassembly. Rapid access to the interior of the pump is provided by a sliding case top. The alarm and operations logs provide a variety of time and date stamped information that will assist in the repair and service of the Horizon Nxt pump.

4.1.3 Upgradability

The Horizon Nxt Modular Infusion System was designed with an eye toward the future. The modular design of the housing and internal assemblies makes access for service or upgrade simple. In addition, some connections are built into every Horizon Nxt for the addition of future options and accessories.

The most likely upgrade choice adds new software to the system. The software is contained in two Erasable Programmable Read Only Memory (EPROM) integrated circuits on the main board, which can be reached by simply sliding back the top cover. The EPROMs are installed in special carrie which protect their pins. Their sockets are polarized so that the EPROMs cannot be mixed up or plugged in backwards. The Biomed Menu can be used to identify the installed software versions.

4.2 FUNCTIONAL DESCRIPTION

The Horizon Nxt Modular Infusion System is a microprocessor-controlled volumetric infusion pump designed with advanced safety and convenience features for both the operator and the service technician. The modular internal design allows for rapid removal and installation of subassemblies for ease of problem diagnosis and repair.

The major subassemblies are: Case Bottom, Power Supply, Main Battery, Half Door/Bezel, Cosmetic Bezel and Key Panel, and Main Board. Inside, the Door Subassemblies are: LED Display Board and LCD Display Module. There are three microprocessors which control most all functions. They are as follows: Door Processor (DP); Management Processor (MP); and the Pump Processor (PP).

Refer to Chapter 5 for a detailed description of items discussed in this section.

4.2.1 Case Bottom

The case bottom is the platform on which the rest of the Horizon Nxt is assembled. Attached directly to the case bottom are the fan, speaker, and the pole clamp. The fan is turned on by management software to cool the pump if its temperature rises too high or with rates >499 ml/hr. The power supply and battery attach to the case bottom with one self-locking nut. The bezel and door assembly slide into place on ribs in the case bottom, and the main board sits on posts above everything else. The case top slides onto the case bottom, locking the whole assembly together.

The case bottom and the other major case parts are painted with a conductive copper paint to provide shielding for the entire system.

4.2.2 Power Supply

The Horizon Nxt power supply board is mounted in a sheet metal chassis with a filtered, AC power inlet connector and a hospital-grade outlet for daisy chaining multiple pumps. The power supply connects to the main board and supplies 16 and 5 volts to the system. The supply is a nominal 30 watt design using switching technology which reduces weight and increases efficiency.

The supply is attached to the case bottom and shielding, with a set of tabs and slots. Once the battery is placed above the power supply, it is made secure with one self-locking nut.

4.2.3 Main Battery

The Horizon Nxt can operate from a built-in 12 volt two amp-hour sealed lead-acid battery. This battery connects to and is charged by a circuit on the main board. The battery fits into a holder which attaches to the power supply and is held in place by the same fastener nut.

4.2.4 Half Door/Bezel Assy.

The Horizon Nxt bezel is a plastic part to which is attached the pump mechanism components and the Air-In-Line block. The door and bezel become one assembly when attached together by the door hinges. The door and bezel assembly is positioned in the case bottom via gasketed tongue and groove joints. On the inside surface, it captures the cassette and tubing and holds the pressure transducer.

4.2.4.1 Half Door/Bezel Mechanism

The Half Door/Bezel Mechanism mechanically controls the flow-rate, volume, and pressure of the fluid delivered. The various important parts of the bezel mechanism are the bezel, the inlet valve, the transfer valve, the restriction valve, the petal module, the refill piston, and the pressure transducer (Figure 2-5). In the following paragraphs, the mechanism is described as it is seen from the front of the pump.

The door of the pump limits the movement of the cassette, and helps to contain the pressure required for pressurized fluid delivery. The door must be closed and securely latched for the pump to operate.

4.2.4.2 Restriction/Outlet Valve

The restriction/outlet valve, (Figure 2-5), is the right-most valve which extends through the bezel. The valve is under servo-control by the pump software and the restriction motor. The purpose of the valve is to provide the proper downstream resistance at the selected operating pressure. The restriction yoke has an optical sensor at the tip, called an optical yoke sensor, giving valve position information to the pump's system.

4.2.4.3 Petal Module

The function of the petal module is to pressurize the delivery chamber of the cassette. The petal module is located just to the left of the restriction valve and has a protective rubber cover. It is pushed forward by the main stepper motor during fluid delivery and retracts as fluid is pushed into the delivery chamber from the refill chamber during the refill operation. The pump system obtains main motor position from the main motor optical encoder.

4.2.4.4 Refill Piston

The refill piston is inversely and mechanically linked to the main motor drive. This allows the cassette to refill while the petal module is delivering. The refill piston is the large disc to the left of the petal module, (Figure 2-5). The face of the piston is a magnet of special construction. It has unusually strong magnetic properties, which allows the piston to remain attached to the metal disk, part of the refill chamber of the cassette, even when refilling from a fluid supply positioned below the inlet of the pump (a negative head height).

4.2.4.5 Transfer and Inlet Valves

The transfer valve controls the transfer of fluid from the refill chamber of the cassette to the delivery chamber and is located between the petal module and the refill piston. The inlet valve controls the flow of fluid into the refill chamber and is located to the left of the refill piston. These two valves are mechanically linked to provide inverse operation and are operated by the pump system via the transfer solenoid.

4.2.4.6 Mechanism Operational Sequence

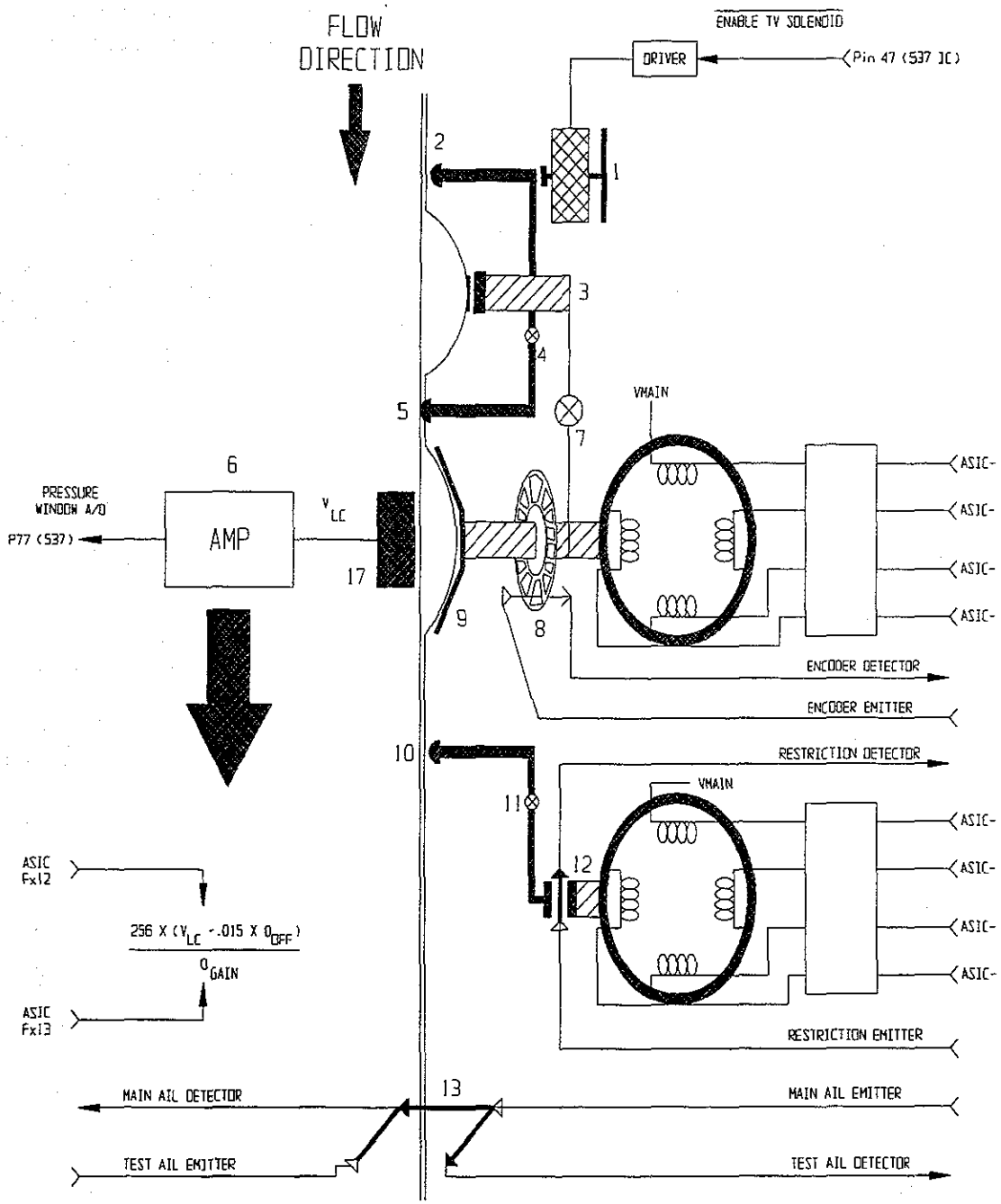


Figure 4-2: Mechanism Description and I/O Map

4.2.4.6 Mechanism Operational Sequence

The Horizon Nxt uses a cyclical volumetric displacement method to deliver fluid. At the beginning of a pumping cycle, the restriction (10) and transfer (5) valves are closed, the inlet (2) valve is open, the petal module (9) is back and the cassette delivery chamber is full (cassette portion attached to 9), the refill piston (3) is forward and the cassette refill chamber (cassette portion attached to 3) is empty.

The petal module (9) is attached to the bezel and is driven by the main stepper motor shaft via a screw thread. Once the RUN Key is pressed, the petal module assembly is driven forward until the selected delivery pressure (6) is achieved, and delivery begins. At the same time, the refill piston moves in the opposite direction, because it is mechanically connected through a pivot point (7). The main stepper motor drives the petal module forward a certain number of steps each cycle to deliver a precise amount of fluid. The delivery is approximately linear; for each main stepper motor step an equal amount of fluid is delivered. As delivery proceeds, the restriction valve opens and closes as the pump software reacts to varying fluid line conditions to maintain constant pressure in the delivery chamber.

As the petal module moves forward under stepper motor control, the refill piston moves back to allow entry of fluid from the container while the inlet valve is open. The encoder wheel (8) is optically monitored to give positive indication of motion. Pressure is monitored by a load cell (17) whose output goes to an amplifier (6). The amplifier output has separate offset and gain controls.

When the delivery cycle is complete, the restriction motor causes the restriction/outlet valve to close through a pivot point (11). The tip of the restriction motor is optically monitored to detect the point just before the valve starts to open. The transfer solenoid (1) energizes, causing the transfer valve to open and the inlet valve to close because it is mechanically connected through pivot point (4), and the petal module retracts as the refill piston moves forward to transfer fluid from the refill chamber to the delivery chamber. When the transfer is complete, the solenoid changes state and a spring forces the transfer valve to shut and the inlet valve to open and the delivery cycle is repeated.

4.2.4.7 Mechanism Interface Board

The mechanism interface board is the connection point between the main board and the bezel and door assemblies. One large connector mates with the main board and from there, connectors are provided for the main stepper motor, main motor encoder, restriction motor, restriction optical yoke, transfer solenoid, air-in-line block, and door assembly.

4.2.4.8 Air-In-Line Block

The air-in-line block is an optical bubble detector which the system uses to prevent pumping air to the patient. The set tubing is pressed tightly into the slot in the block by a spring-loaded pusher in the door. When a bubble above a certain size is detected, the pump will stop pumping and alarm.

4.2.4.9 LED Display Board

The LED display board is the largest PCB inside the door. It contains the red LED display digits and the door processor integrated circuit. The door processor software receives commands from the management processor on the main board, controls the LED displays, processes key panel inputs, controls the LCD display's visual contrast and backlight, controls the display and transducer board memories.

4.2.4.10 LCD Display Module

The LCD display module is a factory-assembled liquid crystal display module containing the actual glass display screen, a printed circuit board containing driver electronics that control the 128 x 64 screen elements, and an electroluminescent backlit panel to allow viewing in low light. This module requires the LCD controller components on the LED board to operate. In order to increase the backlight life span and reduce power consumption, the display is dimmed after three minutes if no keys have been pressed on the face of the pump.

4.2.4.11 Pressure Transducer

The transducer is essential to the operation of the pumping mechanism (Figure 2-5). It measures fluid pressure in the delivery chamber of the cassette. The circuitry amplifies this pressure signal before it is sent to the pump processor on the main board.

The face of the pressure transducer is made of a rubber compound that transmits pressure from the window in the delivery chamber of the cassette to a sensor in the body of the transducer. The transducer face is covered with a special Teflon tape to protect it and reduce friction with the cassette.

4.2.5 Main Board

The main board is the center of the Horizon Nxt electronics system. It contains the management processor, pump processor, and their associated EPROMs. The EPROMs hold the software programs which control the operation of the rest of the system. The main board mounts on four posts which are part of the case bottom, and has connections to the mechanism interface board, option board, main battery, power supply, fan, and speaker.

A switch located at the rear of the board is used to enable or lock out user access to the key panel on the front of the pump while it is running. Also, at the rear of the board is an optical transmitter/receiver pair. These devices send and receive through a plastic window in the rear of the case top, and work in concert with a Serial Data Communications Infrared Module that clips on to the rear of the assembled pump to allow communications with the Horizon Nxt software.

The main board performs all pump mechanism control functions. It has a charging circuits for the batteries, and an interface for an option board. It controls the audio alarm, and has a backup alarm beeper and battery on board. It has special sockets for the two EPROM (Erasable Programmable Read Only Memory) integrated circuits which contain the management and pump processor software programs.

The main board is locked in place by ribs in the case top when it is slid on. This eliminates fasteners, and allows convenient access to the bezel/mechanism and power supply/battery.

5.0 THEORY OF OPERATION, DETAILED DESCRIPTIONS

5.1 POWER SUPPLY BOARD ASSY.

WARNING: USE A LINE ISOLATION TRANSFORMER AND CAUTION WHENEVER WORKING ON AN ENERGIZED SUPPLY. FAILURE TO DO SO COULD RESULT IN BODILY HARM. A large portion of the Horizon Nxt power supply board is connected directly to the AC line and contains high voltages.

The Horizon Nxt power supply has two major sections: an off-line switching supply that converts AC line voltage to 16 volts DC for charging the battery and running the pump, and a DC to DC converter to change either the 16 volt supply or the 12 volt main battery voltage to 5 volts DC for all logic circuits. AC power enters the supply through an electromagnetic interference (EMI) filter with an integral input connector. From there, power is fed to the Daisy Chain outlet and to the power supply board itself. Note that the Daisy Chain outlet is not fused, which is why it should only be used for other Horizon® or Horizon Nxt pumps.

5.1.1 16 Volt Supply

WARNING: DO NOT WORK ON THIS CIRCUIT WITHOUT USING A LINE ISOLATION TRANSFORMER TO ISOLATE THE "NEUTRAL" INPUT CONDUCTOR FROM EARTH GROUND. FAILURE TO DO SO COULD RESULT IN BODILY HARM. The ground reference shown in the primary or high voltage side of the 16 volt supply is not the same as circuit ground throughout the rest of the pump, and it is different from earth ground.

The 16 volt supply section can use a nominal AC line supply of either 120 VAC or 240 VAC. Two jumpers soldered into the board must be removed for 240 VAC operation. The supply has a fuse in each input line, which is required for 240 VAC capability. The Daisy Chain outlet and power cord provided with the 120 VAC system are not applicable for 240 VAC operation. There is then a filter section for removal of electromagnetic interference (EMI). A thermistor, RT1, has a relatively high resistance when cold, which limits the inrush of current when the supply is first plugged in and the filter capacitors are uncharged. Once this happens, the thermistor warms up and its resistance does not affect supply operation. VR1 and VR2 are called Metal Oxide Varistors, or MOV. They absorb high transient voltage spikes which may occur on the line. VR2 is only effective when the 240 VAC jumper JMP1 is cut. Rectifier CR3 acts as a bridge rectifier when configured for 120 VAC and as a half-bridge when configured for 240 VAC.

The control element in this supply is integrated circuit U1. It has a built-in voltage reference and a high frequency oscillator whose frequency (about 50 KHz) is set by R4 and C4. When the AC line cord is plugged in, U1 is supplied start-up voltage through R1. As soon as its Vcc input rises above 8 volts, it begins to operate. U1 turns on field effect transistor (FED) Q1. This connects the primary (pins 1 to 10) of transformer T1 across the high voltage DC supply. Rising current through the inductance of T1 is sensed by resistor R24 until it reaches the peak set by U1, and Q1 is turned off. Two snubber circuits around diodes CR1 and CR2 absorb the high voltage inductive spikes caused by the switching of Q1. These current pulses though T1 create a voltage across the secondary #1 (pins 7 to 8) which is rectified by CR10 and filtered by C24 and L3, to build up to 16 volts. The fuse in series with T1's primary protects the transformer and primary circuits should Q1 fail in the "ON" condition.

Since T1 is the isolating component between the line voltage and the secondary circuit, there is no

direct feedback between the 16 volt output and U1. Instead, secondary #2 of T1 (pins 4 to 5) is used for control. Since secondary #2 is a part of the same transformer, its output is representative of the 16 volt secondary. The output of secondary #2 is rectified by CR3, filtered and fed to U1. As input pin 2 of U1 reaches 2.5 volts, the on-time of Q1 is reduced, and the 16 volt output stabilizes. Over-current protection is provided by the peak-current sensing at R24. Secondary #2 also is rectified by CR4 and used to keep U1 supplied with current during any sags in the high voltage supply.

This 16 volt supply output has a maximum output of approximately 1.8 amps, and is used to power the battery charger and mechanism motors and transfer solenoid in the pump mechanism. When the AC plug is disconnected, the main battery takes over this function. This voltage is distributed to the rest of the pump electronics and is referred to as VMAIN.

5.1.2 5 Volt Supply

The second part of the Horizon Nxt power supply is the 5 volt supply. The controller IC is the same type as used in the 16 volt section, and the circuit configuration is similar, with FET Q2, switching transformer T2 and CR7 rectifying the secondary to get 5 volts out. However, since this is all low voltage circuitry, the 5 volt output is regulated directly by U2. This supply section is powered either by the 16 volt output from the power supply, or the main battery. If the 16 volt supply falls below the main battery level, circuitry on the main board ensures an immediate switchover.

5.2 LED DISPLAY BOARD ASSY.

The LED display board acts as the central connection point inside the Horizon Nxt door assembly. The 34-conductor cable from the bezel assembly brings all signal and power lines to the display board, and from there some are distributed to the transducer and LCD boards.

5.2.1 Door Processor

The heart of the display board is the door processor IC. This is a single-chip microprocessor with an internal program which controls the LED displays, the interface to the membrane key panel, the inverter for the LCD display backlight, and the contrast voltage supply for the LCD display. Secondary functions it performs are reading the nonvolatile configuration memories on both the display and pressure transducer boards. Memory internal to the door processor is used to store display content and other control status information sent from the management processor. This data is lost at power-off and must be restored from the management processor when power is restored.

The door processor behaves as a slave to the management processor on the main PC board. It has a built-in crystal-controlled 5 megahertz oscillator, and is reset by a signal from the management processor. After reset, it turns on the AC indicator LED and waits for commands from the management processor. Communication with the main board is controlled by the management processor and uses four signal lines: SYNCDAT, SYNCCLK, DOORCTS, and DOORRTS. Communications use a synchronous serial format, with the synchronous clock generated by the management processor. If the management processor wishes to send a message to the door processor, it sends one or more bytes with one clock pulse for each bit. If the door processor wishes to send a message to the management processor, it uses DOORRTS to request it, and the management processor uses DOORCTS to indicate its readiness, and the message byte is then transferred by the management processor's clock pulses. These message signals can be observed even when the pump is idle, since each processor sends an "I'm O.K." message every few seconds for safety purposes.

Messages between the two processors have parity bits so that communication errors can be detecte and an alarm generated.

5.2.2 LED Displays

The primary function of the door processor is the control of the LED displays. There are 18 digits of seven segments each and seven individual indicator LEDs. Counting the four decimal points which are used, there are 137 LED segments which must be controlled by the processor. This is accomplished by using a technique called multiplexing, in which a smaller group of digits are turned on, along with the desired segments in those digits, for a short time at a higher than normal brightness. Then another group of digits and segments is turned on using the same processor pins. If this is done rapidly enough, the eye is fooled into thinking that the LEDs are on all of the time at normal brightness.

On the Horizon Nxt display board, the LED digits are divided into five groups. The seven indicator LEDs are treated as if they were another digit. Digit driver U4 is controlled from the door processor so that only one group of digits is fed power at a time. Five shift clock pulses from the door processor move the correct "ON" bit into the digit driver once each multiplex period. At the same time that the digit group is powered up, individual segment drive pins on the processor itself are turned on, so that the desired segments in that group of digits are turned on. Current flow through an individual segment travels as follows: from Vcc (5 volts) supply through transistor Q1 to digit driver U4, from one output of U4 to the LED anode, through the LED to a current limiting resistor, and then through a door processor port pin to ground.

Transistor Q1 is used by the door processor to test LED segments during the multiplexing process If Q1 is turned on by the door processor, the voltage drop across it is very low. To test a single LED segment, Q1 is turned off, and the proper digit group and segment drive pin are turned on. The current flowing through the LED segment produces a voltage drop across resistor R2, and this voltage can be measured by a door processor threshold port pin. This measurement, which can split 5 volts into 16 different levels, can detect if the LED is open. If the segment is bad, then the door processor will send a failure message to the management processor, and an alarm will result. The testing of a segment takes very little time, and is an ongoing process while the LED display is active.

The information to be shown on the LED displays is sent from the management processor and is stored in the door processor internal memory. Brightness of the LED digits is controlled by the percentage of time that the digits are on during multiplexing. The management processor sends brightness commands to the door processor, which makes one row of LEDs brighter than the other to indicate which row will be affected when the key panel is used. When an alarm occurs, the management processor commands the door processor to blink certain digits.

Contents of the door processor memory that controls the LED display contents can be sent back to the management processor for checking display integrity.

5.2.3 Key Panel Interface Assy.

The second most important function of the door processor is to interface with the switches in the membrane key panel. The key panel connects to the display board through two 7-conductor flexible tails. The POWER or on/off switch in the key panel connects straight through to the main PCB to control power-up and power-down sequences. The other key panel internal switches form a five by

six matrix which is connected to the door processor circuitry. Each switch on the panel is connected between one "row" and one "column" of this matrix, which is scanned for pressed keys during part of the display multiplexing process. During a time when they are not driving an LED segment, one of six door processor ports is held low. This pulls one of six key panel columns down to ground through a diode. The five key panel rows are each pulled up to Vcc by a resistor, and are tied to five door processor inputs. If a switch contact on that key panel column is closed when this happens, then that switch's row is pulled low so that one of the door processor's inputs is pulled low. In this way, the software can tell by scanning all six columns which switches are closed. This scanning process is very rapid and is synchronized with the LED multiplexing. If a switch is held down long enough, about $1/30^{th}$ of a second, then the door processor will send a message to the management processor saying that the key has been pressed. If the key remains held down, then a periodic "key still down" message will be sent.

A flexible circuit jumper is part of the key panel tail, and ties one of the five row lines to a special door processor pin. The processor can use this pin to tell which line the jumper is tied to, which tells it the specific key panel type. In this way, future key panels with different switch arrangements or graphics could be identified for use with special software versions.

If the door is open, the management processor will generate audio clicks if the key panel switches are pressed, but no other action will be taken. This is to prevent accidental data or status changes caused by something underneath the open door.

5.2.4 LCD Contrast Voltage

Integrated circuit U3 generates a regulated voltage that is supplied to the LCD display module, which controls the visibility, or contrast, of the display elements on the LCD screen. U3 and the surrounding circuitry takes VMAIN, which ranges from 11 to 16 volts, and generates a negative voltage supply (Vlcd). This voltage is regulated by U3, but it is influenced by two other factors. First, since LCD contrast is affected by temperature, thermistor, CT1, causes Vlcd to change with temperature to match the display. If the display is cold, the voltage should be more negative, if it is warm, the voltage should be less negative. In addition, three output pins from the door processor can shift Vlcd. These three pins can be set to eight different combinations (0-7) which can give eight different levels of Vlcd, which are controlled by software from the User Menu item "Set LCD Contrast." This setting is saved in management processor RAM memory and is restored at power-up. Vlcd has a normal adjustment range from -7 to -8.5 volts.

The door processor uses transistor Q4 to supply Vlcd to the LCD display. At power-up, it is not turned on until the LCD controller has been initialized and the management processor sends an "LCD ON" command to the door.

5.2.5 LCD Backlight Supply

CAUTION: The backlight voltage passes from the display board, through the LCD controller board, and to the LCD display module. If this connection is broken and the inverter is on, it will emit a high frequency audible noise, and it can be damaged by operating this way for any length of time.

The LCD display module contains an electroluminescent panel which is used to backlight the display so it can be viewed in dim lighting conditions. This backlight requires a power supply of 100 volts

AC at 400 Hz frequency. This voltage is generated by a DC to AC converter mounted on the back of the display board. The door processor, commanded by the management processor, controls the VMAIN supply to the inverter, which turns the backlight on and off. An electroluminescent panel has a limited operating life, over which it grows dimmer, so the management software turns off the backlight when no user interface activity is taking place.

5.2.6 LCD Module Assy.

The Liquid Crystal Display module is a combined LCD screen, driver electronics board, and electroluminescent backlight. It is supplied by Epson U.S.A. and is not repairable to the component level. It is a "transflective" type of display, with a built-in reflector for viewing in brighter light, and a transmissive backlight for viewing in dim or no light.

The LCD panel contains 1024 square elements (pixels) arranged as a 128 pixel wide by 64 pixel high array. Control signals for the display are generated by the LCD controller, and are all logic level signals. The actual voltage (Vlcd) that turns on the LCD pixels is a negative voltage (-7 to -8.5 volts) generated on the display board and adjusted (under operator control through the User Menu) by the door processor. This voltage also varies with temperature, since the behavior of the LCD is temperature sensitive. This allows the display to work over a temperature range without requiring adjustments.

The backlight is a solid-state electroluminescent (EL) sheet which glows when energized by a 100 volt AC signal generated on the display board. The glowing phosphors in this panel tend to glow less brightly as time goes on, so the backlight is turned on and off under management software control. After the pump starts running, the backlight is turned off to extend its useful life. Once the backlight is turned off, pushing any key panel key will turn it back on so that the display can be seen in dim light.

5.3 PRESSURE TRANSDUCER

5.3.1 Pressure Transducer Circuits

The pressure transducer converts the pressure applied to its surface membrane to a differential output voltage. The pressure transducer is powered by a constant current source, which is generated by op amp U2A, 2.5 volt reference CR1, and a 1.65K ohm current setting resistor, R3. Op amp U2A maintains 2.5 volts across resistor R3, which results in a constant 1.5 milliamps out of the pressure transducer supply return terminal. The differential pressure transducer output is sensed by op amp U3A, which has unity gain.

5.3.2 Offset, Gain, and Output Circuits

The sensed pressure transducer output signal is amplified and adjusted for offset errors, by means of op amp U2B. Amplifier U2B is constructed as a summing amplifier, with a signal gain of 47.5. Amplifier U2B sums the inputs from the pressure transducer sense amplifier, the 2.5 volt reference CR1, and the -2.5 volt reference CR2. The contribution from the sensed pressure signal is scaled by the ratio of feedback resistor R2 to input resistor R5, which provides a signal gain of 47.5. The contribution from the 2.5 volt reference is scaled by the ratio of feedback resistor R2 to input resistor R8. Therefore, R8 is selected to correct for negative offset errors. The contribution from the -2.5 volt reference is scaled by the ratio of feedback resistor R2 to input resistor R7. Therefore, R7 is selected

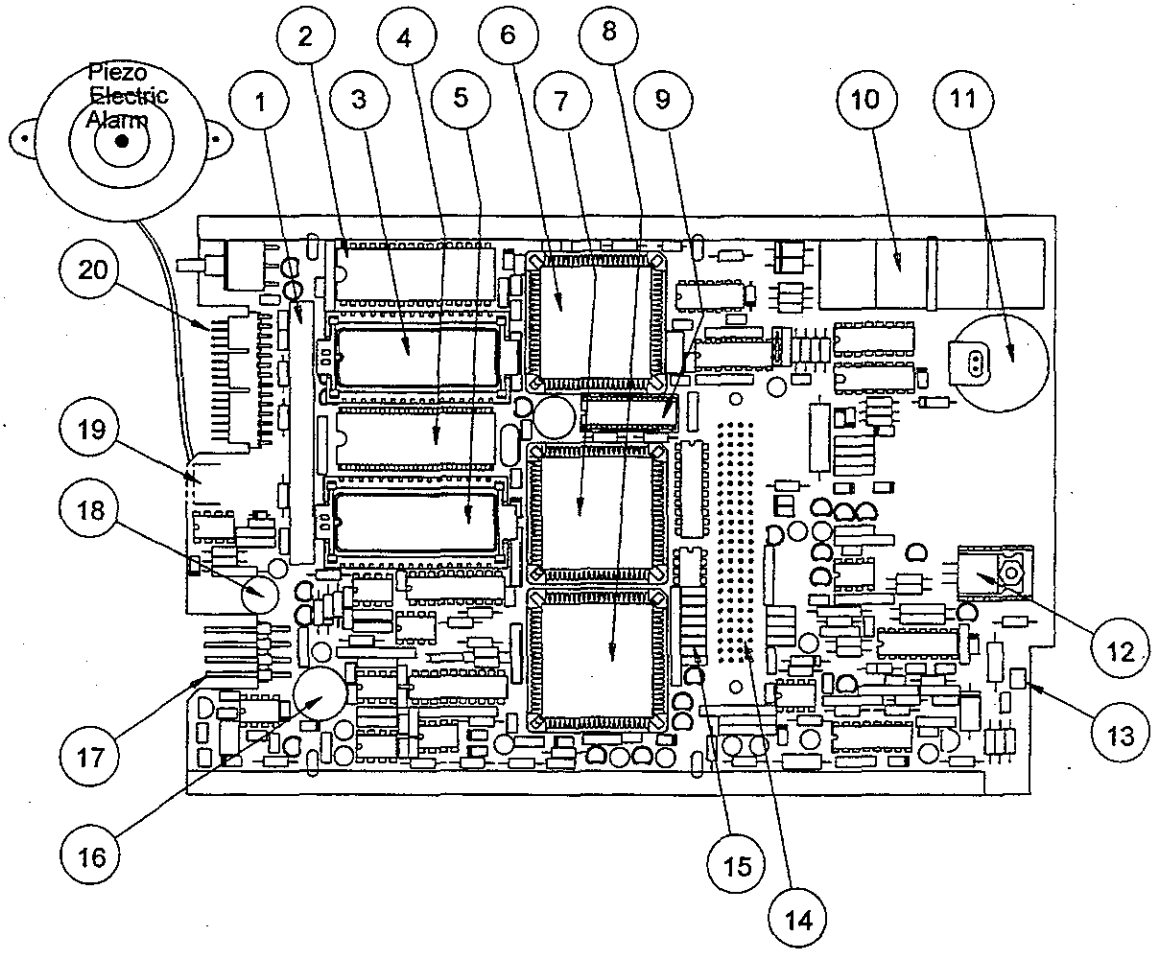
to correct for positive offset errors.

Op amp U3B inverts the offset adjusted pressure signal, to complete the formation of a differential output with maximum range.

5.4 MECHANISM INTERFACE BOARD ASSY.

The mechanism interface board is the connection point between the main board and the bezel and door assemblies. One 100-pin connector mates with the main board and from there, connectors are provided for the main stepper motor, main motor encoder, restriction motor, restriction optical yoke, transfer solenoid, air-in-line block, and door assembly. The connectors are polarized and sized so that the mechanism components cannot be plugged in incorrectly. The door cable assembly is built with special high flex-life ribbon cable to withstand the large number of door operations over the life of the pump.

Figure 5-1: Main Board Layout Description



1. Option Board Connector
2. Pump Processor memory
3. Pump Processor EPROM
4. Management Processor Memory
5. Management Processor EPROM
6. Pump Processor, 80C537
7. Management Processor, V25PLUS
8. ASIC
9. EPLD
10. 4.8 Volt NiCad Battery
11. 3.0 Volt Lithium Battery
12. Main Battery Charger
13. Touch Switch for manual turn off
14. Bezel/Door Connector
15. Motor Drivers
16. Backup Alarm
17. Main Battery Connector
18. Fuse 2, Main Battery Switching
19. Fan/Speaker Connector
20. Power Supply Connector

5.5 MAIN BOARD ASSY.

The main board utilizes a dual processor architecture, for both efficiency and reliability. One of the processors, the management processor, is primarily responsible for interpreting operator inputs, initiating fluid delivery operations, and generating display information. The other processor, the pump processor, is primarily responsible for controlling fluid delivery operations, as directed by the management processor. An application specific integrated circuit (ASIC) generates the waveforms that control the two motors during fluid delivery, as directed by the pump processor. The ASIC also provides all address decoding for the management processor, and provides the interface between the external photo-interrupter LEDs and both processors. A block diagram of the main board's major circuits and their connections to the external subsystems is shown in Figure 4-1. A picture of the main board is included to help identify selected components. See Figure 5-1.

5.5.1 Management Processor

The management processor, U11, is a V25 Plus microcomputer, which is software compatible with the 8086 microcomputer. It uses a 16 bit internal data bus and an 8 bit external data bus. The V25 Plus can directly address 1M byte of memory and 1M byte of I/O. Memory accesses are controlled by Memory Request (MREQ), Memory Strobe (MSTB), and Read/Write (R/W). I/O accesses are controlled by I/O Strobe (IOSTB) and Read/Write (R/W). The V25 has two serial channels and four multifunction I/O ports, including one 8 bit analog comparator port for discrete or analog inputs. The microprocessor operates at a clock frequency of 12 MHz, which is supplied by a crystal and an internal oscillator.

The management processor program is stored in an external 512 K byte EPROM, U13, and data is retained in an external 128K byte RAM, U10. The RAM write line is gated by Memory Strobe with a 74AC11032 NAND gate, U7A, to provide the necessary address setup time. The RAM is backed up with a 3 volt on-board battery, BT2, which is switched in or out by a 691 power supervisory integrated circuit, U5. Therefore, data will be retained in RAM even if the board is removed from the system. Pullup and pulldown resistors on the data bus ensure that an Interrupt 3 instruction will be retrieved by the microcomputer if non-existent memory is addressed.

5.5.2 Door Interface Bus

The management processor communicates with the external door processor via a bidirectional, synchronous serial bus. The management processor uses port pin P14 to transmit and receive data on the data line, and it uses port pin P17 to drive the clock line. The door processor requests permission to transmit a message by raising a flag on the DOORRTS line (management processor port pin P07). The management processor then grants permission to send by raising a flag on the DOORCTS line (management processor port pin P21). The DOORRTS and DOORCTS lines are not used when the management processor sends messages to the door processor, since the door processor is normally ready to receive. The management processor can reset the external door processor with the RESET-DOOR line (port pin 22).

5.5.3 LCD Interface

The management processor can write commands and display data to, and read status and display data from, the external LCD controller, via an 8 bit parallel data path. The 8 bit data path is buffered by a 74HC245 octal bidirectional buffer, U9. The management processor Memory Strobe is gated with

the Read/Write line by two 74AC11032 NAND gates, U7B and U7C, to produce an LCD read and an LCD write line. An LCD select line is generated by the ASIC. It is decoded from management processor memory address space, from 400 hex to 401 hex. A single address line, A0, buffered by a 74AC11032 NAND gate, U7D, provides 2 LCD read addresses and 2 LCD write addresses. This allows the management processor to write LCD commands, write LCD data, read LCD data, and read LCD status.

5.5.4 IR Link

The management processor can transmit to and receive serial data from an external host by means of a full duplex, asynchronous, infrared (IR) communications link. The infrared communication path allows a fluid tight, electrically isolated interface. One of the two serial ports in the management processor is dedicated for this purpose. Transmit data from the management processor serial port output pin is re-driven by PNP transistor Q37, and then routed to an LED, D2, which produces infrared light at 940 nM. The LED is positioned at the rear of the main board, facing a window that is transparent to infrared light. An optional external IR communications module converts the infrared transmit data to RS 232 levels, and completes the transmission to an external host. RS 232 data from the host is similarly converted to infrared light by the external IR communications module, and detected by a phototransistor, D3, located at the rear of the main board. This data is routed directly to the management processor serial port input pin. The data is sent as ASCII text using a baud rate of 9600, no parity, 8 data bits and 1 stop bit. With this format an entire log, alarm or operation, can be downloaded in approximately 90 seconds. Refer to the PC Docking Manual, Part No. 950441.

5.5.5 Pump Processor

The pump processor is an 80C537 microcontroller, U3, which is based on a superset of the 80C31 architecture. With 16 address bits, the 80C537 can directly address 64K bytes of program memory and 64K bytes of data memory. Eight output pins are dedicated to the upper eight address bits, but the lower eight address bits are multiplexed with the 8 bit data bus. Therefore, the lower eight address bits must be stored in the 74HC373 latch, U16, with the falling edge of Address Latch Enable (ALE) before the eight data bits are presented on the same lines. Program memory fetches are controlled by Program Store Enable (PSEN), data memory reads are controlled by Read (RD), and data memory writes are controlled by Write (WR).

The pump processor program is stored in an external 64K byte EPROM, U6, and data is retained in an external 128K byte RAM, U1, although only half the RAM can be accessed. Pulldown resistors on the data bus ensure that a NOP instruction will be retrieved by the microcontroller if nonexistent memory is addressed.

In addition to its address and data ports, the 80C537 has five 8 bit multifunction I/O ports, two serial channels, and 12 A/D inputs. The 80C537 operates at a clock frequency of 12 MHz, which is supplied by a crystal and an internal oscillator.

5.5.6 Interprocessor Communications Bus

The management processor and the pump processor communicate with one another through dedicated full duplex asynchronous serial ports. The management processor can transmit messages to the pump processor at any time over the V25TO537 line, and the pump processor can transmit messages to the management processor at any time over the 537TOV25 line.

5.5.7 ASIC

The ASIC, U19, interfaces with both the management processor bus and the pump processor bus. It performs all address decoding for the management processor, performs I/O address decoding for the pump processor, generates stimuli for external sensors, and generates motor drive waveforms for the main motor and restriction motor.

5.5.7.1 Address Decoding and Stimuli

The AIL LED, test AIL LED, main motor encoder LED, restriction valve LED, Anti-Freeflow Clamp LED, and the door switch can all be energized by either the management processor or the pump processor.

5.5.7.2 Motor Controller

The ASIC receives motor commands from the pump processor bus, and generates pulse width modulated (PWM) waveforms for the main motor and the restriction motor. Both motors are four phase, unipolar stepper motors. A single command from the pump processor can result in no more than a single step from a single motor, so the motors are always under strict processor control. The eight PWM motor waveforms are re-driven by eight N-channel FET's with transient suppression diodes. The resulting drive signals are then routed to the motor windings. The eight PWM motor waveforms in the ASIC can be completely inhibited by the LATALARM signal from the EPLD. See Section 5.5.12.2 "Power Controller EPLD" for a description of LATALARM.

The ASIC controls the duty cycle of the PWM waveforms, as directed by the pump processor, which in turn determines the average current through the motors. The pump processor can also command the ASIC to ramp the duty cycle of the PWM waveform up or down over a selectable period of time, at the beginning or end of a motor step. This is done to reduce the acoustical noise when a motor step is applied.

5.5.7.3 ASIC Timers

The ASIC also contains two programmable timers, one for each motor, to ensure that the motor stepping rates selected by the pump processor are accurate. Any pending main motor step command is automatically executed when the main motor timer times out. In addition, the main motor timer issues interrupts to the pump processor at three different points: when the timer times out, three timer clock periods before the timer times out, and seven timer clock periods before the timer times out. The main motor timer clock period can be programmed to be either 341 microseconds or 2.73 milliseconds. The restriction motor timer issues interrupts to the pump processor only when its timer times out. Any pending restriction motor step command is automatically executed at that time. The restriction motor timer clock period is 685 microseconds.

5.5.8 Transfer Valve Solenoid Driver

The pump processor generates the PWM waveform for the transfer valve solenoid by means of a built-in timer/comparator circuit, using port pin P4.7 . The pump processor reduces the duty cycle of the waveform after initial pull-in of the solenoid, in order to minimize power consumption. The PWM motor waveform is inverted by a P-channel FED, Q3, and driven by an N-channel FED, Q32,

with a transient suppression diode, CR30. The resulting drive signal is then routed to the solenoi winding. The other side of the solenoid is connected to VMAIN.

5.5.9 Temperature Controller

The pump processor monitors the air temperature inside the case with a thermistor, TH1, through A/D port pin P7.0. If the temperature exceeds a preset threshold, the pump processor turns on a cooling fan, through port pin P6.4. The fan signal is re-driven by an N-channel FED, Q13, with a transient suppression diode, CR24, and a 7.5 volt zener diode, CR18, before being routed to the fan motor.

5.5.10 External Sensor Interface

5.5.10.1 Panel Lock Out Switch

The panel lock out switch is a single pole, double throw, momentary switch, which is mounted on the main board. It is accessible to the user through a flexible membrane in the rear of the case. The state of the switch signal is monitored by the management processor, via port pin P05. The software toggles between the lock out mode and the non-lock out mode with each depression of the switch.

5.5.10.2 Door Switch

The door switch is a single pole, double throw, magnetically operated switch, which is mounted in the bezel. The switch is closed by means of a magnet in the door whenever the door is closed The state of the switch is monitored by the management processor, via port pin P01. The switch is directly energized by the STIM signal, which can be generated by either processor via the ASIC. Therefore, the management processor can distinguish between a switch signal that is stuck low and a real closed door condition, by toggling the STIM signal.

5.5.10.3 Encoder and Restriction Valve

The position of the main motor is determined by counting pulses from an encoder wheel mounted to the motor shaft. The motor is first initialized to a known position by retracting it to its extreme limit. The pulses are generated by a photo-interrupter assembly, which detects the alternate spokes and holes in the encoder wheel. The encoder output signal remains high for approximately four main motor steps and low for approximately six main motor steps. This output, ENCODERSEN, is received by inverting schmitt trigger U2 on the main board, and then routed to both processors.

The position of the restriction valve is determined by counting restriction motor steps. The restriction valve is first initialized to a reference position (fully closed position) by moving it to the position where the restriction motor shaft makes initial contact with the spring loaded valve linkage. At this point, the output from a photo-interrupter assembly in the valve link makes a transition in logic levels: high for contact, low for no contact. This output, RESTRSEN, is received by inverting schmitt trigger U2 on the main board, and then routed to both processors.

The LEDs in both photo-interrupter assemblies are connected in series, and energized by the STIM signal generated in the ASIC. The STIM signal is re-driven by transistor Q32 and current

limited with a 220 ohm resistor before being routed to the LED's.

5.5.10.4 Air-In-Line Block

Air bubbles in the line are detected by means of the air-in-line block. The air-in-line block printed circuit board contains two separate infrared LED/photosensor pairs, with current limiting LED resistors. One pair, the AIL pair, utilizes the different indices of refraction of air and liquids to detect air bubbles in the line. Its LED is energized by the AILLED signal generated in the ASIC. The AILLED signal is re-driven by transistor Q31 before being routed to the AIL board. The output of this pair, AILSEN, is received by comparator U4A and then routed to both processors. In normal operation, AILSEN is high for air and low for liquids.

Another LED/photosensor pair, the TESTAIL pair, is used to test the operation of the AIL LED and photosensor. The TESTAIL LED is positioned to emit infrared light directly onto the AIL photosensor. The AIL output signal is high when the TESTAIL LED is on. The TESTAIL LED is energized by the TESTAILLED signal generated in the ASIC and re-driven by transistor Q30 before being routed to the AIL board. The TESTAIL photosensor is positioned to detect infrared light emitted by the AIL LED. Its output signal, AILTESTSEN, is received by comparator U4B and then routed to both processors. AILTESTSEN is high when the AIL LED is on.

5.5.11 Power

The main board circuits are powered by the external power supply, an onboard voltage regulator, an onboard power converter, the main battery, and two onboard batteries.

5.5.11.1 VSUPPLY

When the Horizon Nxt is plugged into an AC outlet, the power supply generates 16 volts on the VSUPPLY line. The power supply then uses VSUPPLY to generate 5 volts on the VCC line. Therefore, when the Horizon Nxt is not plugged in, the power supply can generate the 5 volts. The main board provides that DC source by means of an external main battery, which can be connected to VSUPPLY under software control, through 2 amp fuse FU2, FET Q35, and diode CR31. Since the power supply also sources 16 volts through a diode, VSUPPLY will reflect the value of the higher of the two sources: 16 volts when the Horizon Nxt is plugged in, 12 volts when it is turned on but not plugged in, and zero when it is not turned on and not plugged in.

5.5.11.2 VMAIN

All of the VSUPPLY current that is used by or distributed by the main board is measured through a series .05 ohm resistor, R44, and op amp U17A. The pump processor monitors the op amp output through A/D input P7.3. The node on the load side of the .05 ohm resistor is called VMAIN.

5.5.11.3 VBATT

The external 12 volt lead-acid battery is connected to the main board through a 2 amp fuse, FU2. The node on the load side of the fuse is called VBATT. The battery voltage is measured by op amp U22A, through two sense wires provided for that purpose: BATTSEN+ and BATTSEN- . The output of the op amp is monitored by the pump processor, through A/D input P7.2.

In addition to the analog measurement of VBATT, two comparator circuits are provided to monitor the condition of the battery. The LOWBATT signal is generated by comparator U26A and a 2.5 volt reference, VR2, whenever VBATT is less than 10.5 volts. LOWBATT is connected to the management processor non-maskable interrupt input, P10, and to pump processor input P3.2. The DEADBATT signal is generated by comparator U26C and voltage reference VR2 whenever VBATT is less than 10.3 volts. DEADBATT is connected to the power controller EPLD, U8.

The main board maintains the charge on the main battery by means of a UC3906 battery charger integrated circuit, U20, which is powered by VSUPPLY. The UC3906 automatically switches between three different charge states, depending on the condition of the battery: a high current bulk-charge state, a controlled overcharge state, and a precision float-charge, or standby, state. The pump processor can disable the charger during battery operation.

5.5.11.4 V+

V+ is produced from 12 volts or 16 volts on VMAIN by an onboard 78L08 eight volt voltage regulator, VR1.

5.5.11.5 V-

-8 volts is produced from 12 volts or 16 volts on VMAIN by an onboard 1054 switched capacitor voltage converter with regulator, U24. The -8 volt regulator output is gated by FET Q33, which outputs -8 volts on the V- line. Q33 is provided to ensure that V- cannot become positive during power-up.

5.5.11.6 VMEM

A 3 volt, 280 ma-hr, nonrechargeable lithium battery, BT2, is provided on the main board, as a backup power source for VMEM. VMEM powers the management processor RAM, U10, and the time-of-day integrated circuit, U18. A 691 power supervisory integrated circuit, U5, connects either the 3 volt VCC or the 3 volt battery voltage to VMEM, whichever is higher. Therefore, information stored in the RAM and the time-of-day integrated circuit is maintained, even when the main board is removed from the Horizon Nxt.

5.5.11.7 VBKUP

A 4.8 volt battery pack, BT1, is provided on the main board, as a backup power source for VBKUP. The battery pack consists of four rechargeable, 1.2 volt, 100-110 ma-hr, nickel-cadmium batteries. VBKUP powers the backup alarm, the power controller EPLD, the power switch circuits, the 2.5 volt reference, and the main battery threshold detectors. Therefore, the backup alarm will be operable, even if the Horizon Nxt is not plugged in and the main battery is dead. The 4.8 volt battery pack is charged by diode CR3 and resistor R2 whenever power is available from VSUPPLY.

VBKUP normally obtains power from VCC, through diode CR5, whenever VCC is available. It obtains power from the 4.8 volt battery pack or VSUPPLY through diode CR6 and FET Q36 only if the Horizon Nxt has been turned on. It also obtains power from VBATT through resistor R23, diode CR17, and FET Q36 if the Horizon Nxt has been turned on.

5.5.12 Power Control Circuits

When the Horizon Nxt is turned off and not plugged into an AC power source, pressing the power switch will activate the circuits that apply main battery power to the power supply and to the main board. Then, when the power supply applies VCC to the processors, they will detect the active power switch signal, and begin normal operation. The next time the processors detect an active power switch signal, they will prepare the Horizon Nxt for power-down, and activate their battery-disconnect signals. When the power controller EPLD receives battery-disconnect signals from both processors, it will disconnect the main battery. At this point, the instrument will be unpowered again. When the Horizon Nxt is plugged into an AC power source, power-up and power-down proceeds logically the same as when it is not plugged in, except that the electronics remain powered. That is, the circuits remain powered when the Horizon Nxt is turned off, but only the main battery charger and the AC LED indicator are active.

5.5.12.1 Power Switch Circuit

The power switch is a simple membrane switch located on the front key panel, with one side connected to ground. The other side is connected through diode CR21 to the gate of FET Q36. When the power switch is pressed, Q36 immediately applies power from VSUPPLY, VBATT, or the 4.8 volt battery pack, to VBKUP. VBKUP then powers the remainder of the power control circuits, thus enabling the subsequent stages of the power-up process.

The power switch is also connected through diode CR20 to the input of comparator U26D, resistor R63, and capacitor C64. When the power switch is pressed, the comparator output, SW, is immediately asserted. When the switch is released, R63 and C64 delay the deactivation of the SW signal for approximately 500 milliseconds. Therefore, short pulses from the power switch are stretched to a usable length of time. The SW signal is routed to both processors and the power controller EPLD, U8.

5.5.12.2 Power Controller EPLD

The power controller electrically programmable logic device (EPLD), U8, performs several different functions. It controls the connection of the 12 volt battery to VSUPPLY, it controls the connection of the 4.8 volt battery pack to VBKUP, it activates the backup alarm in response to various input conditions, and it performs address decoding for the pump processor. When the EPLD detects the SW signal during the power-up process, it asserts the CONVBKUP and the CONVBATT signals. The CONVBKUP signal turns on FET Q1 after an approximate 50 millisecond delay, which is induced by resistor R12 and capacitor C6. FET Q1 then enables FET Q36, which connects the 4.8 volt battery pack to VBKUP. At this point, the operator can release the power switch, and the power-up process will continue. The CONVBATT signal is inverted by FET Q19, which enables FET Q35, which connects VBATT to VSUPPLY through diode CR31. The next press of the power switch will not normally affect the EPLD directly. However, the processors will interpret the key press as a request for power-down. After preparing the instrument for power-down, the management processor will assert the DISCONA signal via port pin P06, and the pump processor will assert the DISCONB signal via port pin P5.7. When both processors have asserted their disconnect signals, the EPLD will disconnect the 4.8 volt battery, unless the backup alarm has been activated, and it will disconnect the main battery.

The EPLD activates the backup alarm via the BKUPALARM signal whenever both CONVBK-

UP and RESET are asserted. Therefore, RESET normally causes a short beep from the backu alarm circuit, prior to the chime from the primary alarm circuit, when an unplugged instrumen is first turned on. The EPLD also activates the backup alarm whenever the EPLD latched output signal, LATALARM, is asserted. Pressing the power switch after LATALARM has been asserted will cause the EPLD to immediately silence the alarm, and disconnect both the 4.8 volt battery and the main battery. LATALARM is asserted under four different conditions, which are described below.

CONDITIONS RESULTING IN LATALARM SIGNAL

1. The pump processor issues an ALARMON signal, via port pin P5.2.
2. The management processor issues a SHUTDOWN signal, via port pin P02.
3. Comparator U26C generates a DEADBATT signal. DEADBATT also causes the EPLD to disconnect the main battery, to protect it from permanent damage.
4. An extraneous RESET signal is generated after the normal power-up RESET. The possible causes of extraneous RESET's are described in the Power Supervisory Circuit section.

The EPLD also decodes addresses for the pump processor. The single decoded output, 537RAM, is routed directly to the pump processor RAM and the ASIC, without diode protection. Therefore, the 537RAM output line is forced low by the RESET line whenever VCC is not available, to avoid the possibility of sourcing an unpowered component through an input pin when the EPLD is powered by the 4.8 volt battery.

5.5.12.3 Power Supervisory Circuit

The 691 power supervisory circuit, U5, performs several functions. It generates resets under various input conditions and controls backup power for the management processor RAM and the time-of-day circuit.

The 691 constantly monitors VCC, and generates a minimum 35 millisecond reset on the RESET line if VCC falls below 4.5 to 4.75 volts. Therefore, RESET is always asserted on initial power-up and during subsequent negative glitches on the VCC line. Reset is also generated by the overvoltage detection circuit whenever VCC exceeds 5.32 to 5.6 volts for 4-15 milliseconds. See the Section entitled "Overvoltage Detection Circuit." The 691 also asserts the RESET line whenever its watchdog circuit times out. The watchdog time-out period is 1.6 seconds. The watchdog circuit is normally prevented from timing out by pulses generated by the pump processor, via port pin P6.0. A reset can also be forced by holding the TESTRESET line from the option connector either low or high for 1.6 seconds. This normally open-circuit line is connected to the 691 watchdog input, along with the watchdog input signal from the pump processor.

Both VCC and the 3 volt battery, BT2, are connected to the 691. During normal operation, the 691 connects VCC to the VMEM line, which provides power to the management processor RAM, U10, and the time-of-day integrated circuit, U18. The 691 BATON output signal also enables a separate PNP transistor, Q5, which provides additional current from the VCC line to VMEM. However, when VCC falls below the voltage level of the 3 volt battery, the 691 asserts the RESET signal, and switches the 3 volt battery power onto the VMEM line instead. The 3 volt battery power is sufficient to maintain the data in the management processor RAM and to maintain the current time in the time-of-day integrated circuit. The RESET line is also routed to one of the management processor RAM enable inputs in order to inhibit writes when VCC is

low.

5.5.13 Voltage References

Two voltage references are supplied on the main board. A 5 volt reference voltage is generated by a 1029 integrated circuit, CR35, which is powered by V+. The source current from V+ passes through a red indicator LED, D1, and a voltage dropping resistor, R38, before reaching the 1029. Therefore, LED D1 provides an "ON" indication for service technicians without using additional power. The 5 volt reference is used by the A/D converter inside the pump processor, the analog comparators inside the management processor, the offset DAC in the pressure signal circuits, and the thermistor in the temperature control circuit.

A 2.5 volt reference voltage is generated by a 2425 precision virtual ground integrated circuit, VR2, which is powered by VBKUP. The 2.5 volt reference is used by the LOWBATT and DEADBATT comparators, U26A and U26C.

5.5.14 Pressure Signal Circuits

The pressure signal circuits receive the differential output signal from the pressure transducer, VPRESS+ and VPRESS-, and perform several processing operations before presenting the results to the A/D converter inside the pump processor. The differential input signal is first converted to a single ended signal by op amp U22B. Then the single ended signal is level shifted and amplified under control of the pump processor. The shifted and amplified signal is then routed through a diode/resistor clamping matrix, and presented to the A/D converter inside the pump processor. The software controlled level shifting and amplification allows the pump processor to examine minute details imposed on relatively large scale pressure signal waveforms with increased resolution.

5.5.15 Variable Level Shifter

The pump processor uses half of a 7528 dual DAC, U23, and op amp U21B to generate a variable offset voltage for the level shifting process. A -3.84 volt reference voltage for the DAC input is generated from the 5 volt reference voltage by op amp U25A. This allows the DAC to generate a variable offset voltage between zero and 3.84 volts, in 15 millivolt increments. The offset voltage from U21B is subtracted from the single ended pressure signal by op amp U25B.

5.5.16 Variable Gain Amplifier

The pump processor uses the other half of the 7528 dual DAC, U23, and op amp U21A to amplify the level shifted pressure signal by a variable amount. Since the DAC is inserted in the feedback path of op amp U21A instead of its input path, the gain is inversely proportional to the DAC setting. Thus, the gain can be varied from 256/255 to 256/1. The output of the variable gain amplifier is clamped by means of a diode/resistor matrix, to protect the A/D inside the pump processor from excessive voltages. Refer to Chapter 7, Section 7.7.1.1, "Testing the Pressure Transducer A/D Offset."

5.5.17 Time of Day

The main board maintains the current time by means of a 1202 serial timekeeper integrated circuit, U18, with a separate 32.768K Hz crystal. The 1202 counts seconds, minutes, hours, day, month, and year. The time-of-day select line, TOD, is generated and latched in the ASIC. It is controlled

by bit four of the command byte that is located at address 2200 hex in the management processor I/O space. The 1202 is powered by VMEM, which is backed up with a 3 volt battery when VCC is not available.

5.5.18 Audible Alarms

5.5.18.1 Primary Alarm

Both primary and backup audible alarm circuits are provided on the main board. The primary alarm uses an external 8 ohm speaker. It is driven by a 7052 full bridge speaker driver integrated circuit, U12, which is fed by a chime generator circuit. The chime generator is built around op amp U15A, which receives a software controlled volume control signal on its positive input terminal and a software controlled pitch signal on its negative input terminal. The pitch signal is a square wave transmitted from management processor port pin P15. The volume control signal is an exponentially decaying waveform derived from a 1.5 microfarad capacitor or a 10 microfarad capacitor, which are both connected to the positive terminal of op amp U15A through a diode array and a 100 K ohm input resistor. The 1.5 microfarad capacitor, C60, is used to generate short decay time volume control waveforms, for maximum chime effect. The 10 microfarad capacitor, C63, is used to generate longer decay time volume control waveforms, for a steady tone effect. C60 is charged up to a software controlled initial value by management processor port pin P03. C64 is charged up to a software controlled initial value by management processor port pin P04.

The speaker current is sensed by a series 0.2 ohm resistor, R35, and amplified by op amp U15B. The amplified speaker current signal is routed to a peak detector, consisting of series resistor R33, series diode CR33, storage capacitor C53, and drain resistor RP15-6. The peak detected speaker current signal is monitored by the management processor, via an analog comparator input, PT6.

5.5.18.2 Backup Alarm

The backup alarm uses an onboard or external piezo sound generator with built in oscillator, AL1. AL1 is driven by a 1026 voltage doubler integrated circuit, U27, which receives input power from the VBKUP line. The backup alarm is turned on by the BKUPALARM signal from the power controller EPLD, U8. See the Power Controller EPLD section for a description of the BKUPALARM signal. The BKUPALARM signal turns on FET Q23, which completes the ground circuit for voltage doubler U27 and piezo sound generator AL1. Since both the EPLD and the voltage doubler are powered by VBKUP, which is backed up with an onboard 4.8 volt battery, the backup alarm can continue to sound even if the instrument is unplugged and the main battery becomes discharged. This alarm can be turned off manually by touching the 2 contacts on the main PCB. See Figure 5-1, Item 13.

5.5.19 Overvoltage Detection Circuit

The Horizon Nxt overvoltage detection circuit utilizes comparator U4D to compare a scaled VCC against the 2.5 volt voltage reference. VCC is scaled by voltage divider R5/R6, and filtered by a 0.1 microfarad capacitor, C2. When VCC reaches the trip point voltage, comparator U4D transmits a signal to the power fail input pin of the 691 power supervisory circuit, U5. The trip point is between 5.32 volts and 5.6 volts, with a nominal value of 5.46 volts. The power fail output pin and the reset

output pin of the 691 power supervisory circuit are connected together. Therefore, any positive voltage excursion on VCC with sufficient amplitude and duration will result in a board reset, which will cause the power controller EPLD, U8, to activate the backup alarm.

The overvoltage detection circuit is designed to filter out voltage spikes shorter than 4 milliseconds, and to generate a board reset signal for voltage spikes longer than 15 milliseconds. The 2.5 volt voltage reference, the power controller EPLD, and the backup alarm are powered by VBKUP. Comparator U4D is powered by VCC, and is guaranteed to operate properly with input power from 3-15 volts.

5.6 AIR-IN-LINE BOARD ASSY.

Air bubbles in the line are detected by means of the air-in-line block. The air-in-line block PCB contains two separate infrared LED/photosensor pairs, with current limiting LED resistors. One pair, the AIL pair, utilizes the different indices of refraction of air and liquids to detect air bubbles in the line. Its LED is energized by the AILLED signal generated on the main board. The output of this pair, AILSEN, is used by the main board to determine whether air is present in the line. In normal operation, AILSEN is high for air and low for liquids.

Another LED/photosensor pair, the TESTAIL pair, is used to test the operation of the AIL LED and photosensor. The TESTAIL LED is positioned to emit infrared light directly onto the AIL photosensor. The AIL output signal is high when the TESTAIL LED is on. The TESTAIL LED is energized by the TESTAILLED signal generated on the main board. The TESTAIL photosensor is positioned to detect infrared light emitted by the AIL LED. Its output signal, AILTESTSEN, is used by the main board to determine whether the AIL LED is working. AILTESTSEN is high when the AIL LED is on.

5.7 SYSTEM OPERATION

5.7.1 Power-up

The Horizon Nxt has two powered-up conditions. If the pump is off and unplugged, and then is plugged in, the power supply powers-up the system and the microprocessor programs start running. The management and pump processors initialize their internal memories, and wait for the POWER Key on the key panel to be pressed. The pump processor continuously pulses the power supervisor circuit to prevent a watchdog reset. The management processor releases the reset line to the door, and the door processor turns on the single green AC LED indicator and waits for the first command from the management processor. The LCD contrast voltage is not turned on, so the LCD display remains blank. No messages are sent, and no other processes are active.

If the pump is not plugged in, and the POWER Key is pressed, the power control circuitry, powered by the 4.8 volt backup battery, causes the main battery to be temporarily connected to the power supply, energizing the 5 volt switching regulator and generating Vcc to the whole system. This starts up the main board processors, which both detect that the POWER Key is pressed. The EPLD, without software control, latches the main battery supply on. From this point, DC or AC power-up actions are the same.

At this point, the door processor is reset by the management processor, and the green AC LED indicator is turned on again. If the pump is actually running on the main battery, a later message from the management processor causes the LED indicators to switch to indicate BATT.

Both main board processors test internal and external RAM memories as well as the program EPROM contents. Any memory failure results in a system alarm. The management RAM is battery backed by the 3 volt battery, and stores important data from when the pump was last turned off. This data is tested to be sure that its contents have not been altered. The management processor reads the contents of the time-of-day clock and alarms if the date or time data is invalid.

Messages start to be exchanged between management and pump processors. Periodic "I'm O.K." messages detect if either software ceases to work correctly. If this happens, the management and/or pump processor will sound an alarm.

The management processor sounds the chime sound of the audible alarm. The current drawn by the alarm driver is tested, and if the current read is too low, the backup alarm is turned on and a system alarm is generated. Refer to Alarm Code number 71 in Appendix B: Troubleshooting Guide.

The pump processor initializes the pumping mechanism circuits in the ASIC device. If the pump door is closed and the air-in-line block tube detector indicates that a set is in place, the restriction motor home position is located as well. If not, then this is done at RUN time.

The management processor sends commands to the door processor to initialize the LED display digits. Data displayed is determined by the data stored in management RAM and the settings from the Biomed Menu that concern data retention and start-up values. The LCD controller is initialized by management processor commands, and LCD contrast voltage and backlight are turned on. "I'm O.K." messages start to flow between door processor and management processor, and any failure in the exchange will result in either an audible alarm or an "ERR" message on the LED displays.

Once all power-up testing has been completed and there are no alarms, the pump goes into the Hold state, and awaits operator action.

5.7.2 Hold State Operation

When the microprocessor is in the Hold state, the yellow HOLD indicator is illuminated, and the Information Display indicates the time left and volume delivered values, along with the status, setup instructions or any relevant alarm messages. The Primary and Piggyback Rate and Volume To Be Delivered displays indicate the appropriate data as determined by the software power-up defaults, and previous saved data. If either Piggyback rate or Piggyback volume data is zero, then the Piggyback display remains blank. If not, it is illuminated at a reduced brightness to indicate that the Primary display digits would be changed if the DATA Keys are operated.

The management processor uses the state of the door and the air-in-line tubing detector to determine which prompt to show on the Information Display.

If the HOLD Key has been pressed in response to an alarm condition then the appropriate alarm message will be shown at the bottom of the LCD Information Display until either RUN Key is pressed.

At any time while in the Hold state, the rate and volume to be delivered values may be changed by pressing the keys below the display digits. If a key is pressed once, the audible alarm will beep once, and the corresponding digit will increase or decrease by one, or roll over or under if the maximum or minimum value has been reached. If a key is pressed and held, the corresponding digit will continue to change and the alarm will beep, at a rate of three times per second. Normally, either rate can

be set from zero to 999.9 ml/hr, while the volume to be delivered can be set from zero to 9999.9 ml. Leading zeros are not displayed. The pump will not begin operation, however, if either the Rate or the Volume To Be Delivered display of the current row is set to zero. If two keys are pressed simultaneously there will be no response.

In the Hold state, pressing the MENU Key gives access to the Main and Alternate Menus and all of the features available there. Once the pump is running, only some Main and Alternate Menu choices are available.

During the Hold state, software internal tests are performed periodically and any problems that are detected generate an immediate alarm. After 20-30 seconds have transpired while in the Hold state without key presses, the word "HOLd" is displayed in the unused VTBD channel of the LEDs. In addition, if the door is closed, a timer is activated which causes a "Hold Time Exceeded" alarm if the pump remains on hold without key presses for more than 3 minutes, unless Hold Extender option is being utilized. (See the Horizon Nxt Operation Manual for an explanation of the Hold Extender option.) If the door is opened, the timer will be deactivated until the door is closed. Once the door is closed the timer is reset for another three minutes. Once the "Hold Time Exceeded" alarm is activated, the HOLD Key must be pressed to silence the audible alarm, return the pump to the Hold state, and reset the timer for another three minutes.

If the door is open, the power can be turned on but all other key panel switches can only cause audible clicks. This is to prevent accidental data or status changes. If the door is open, the pump is on battery power and in the Hold state, the system will automatically turn of the device after approximately 20 minutes to conserve the battery.

5.7.3 Run State Operation

When either the PRIMARY RUN or PIGGYBACK RUN Key is pressed, several tests are performed before fluid delivery begins. First, if either the Primary Rate or Volume To Be Delivered display is set to zero, or either of the Piggyback Rate or Volume To Be Delivered displays are zero and the PIGGYBACK RUN Key was pressed, the appropriate zero display digit is illuminated, a warning message is displayed, the ALARM INDICATOR is illuminated, and the audible alarm sounds. If the door is opened after a RUN Key is pressed, a "Door Open" alarm is generated. To clear the alarm close the door, press the HOLD Key, and press the RUN Key again.

The management processor then sends delivery commands to the pump processor to begin pumping.

Before it begins, the pump processor checks the air-in-line block and flow clamp detector. If it indicates that a tube is not present, a "Flow Clamp Position" alarm is generated.

The pump processor moves the restriction motor to determine its home reference position. This position is the point where the restriction valve rests upon the channel in the cassette, and the optical yoke sensor beam detects the end of the restriction motor shaft. Any mechanical or electrical problem which prevents this will generate an alarm.

The pressure transducer is read by the pump processor. If this reading is above an acceptable limit, and the door is closed, the pump processor assumes that there is high pressure caused by the loading of a full cassette. The transfer solenoid is energized several times to attempt to let the pressure be relieved back upstream. If the reading (or pressure) cannot be relieved, an "Upstream Occlusion"

alarm is generated. If there is a high transducer reading and the door is open, then a system alarm is generated.

If these tests are successful, the pump processor computes the various motor timing values required for accurate delivery and pumping begins.

Pumping is carried out in repeating cycles, at the rate selected by the operator. If the rate is 400.0 ml/hr or greater, the occlusion pressure limit is raised to 400 mmHg to compensate for dynamic pressures in the set. All events during the cycle are initiated by the pump processor. The initial conditions when the cycle starts are that the main motor is retracted to the point where delivery begins, the refill piston is fully forward, the transfer solenoid is not energized, so that the transfer valve is closed and the refill valve is open, and the restriction valve is closed.

The main motor is first moved forward at a high speed to pressurize the fluid in the delivery chamber. When the cassette is installed into the mechanism, and the door is shut, an undetermined amount of fluid is held within each of the two chambers. A full delivery chamber is required for proper pumping action, so that if the chamber does not come up to pressure in a certain number of main motor steps, the pump processor tries to fill the chamber from the refill chamber. This is accomplished by stopping the main motor and actuating the transfer solenoid, which opens the transfer valve, and closes the inlet valve. Then, the main motor draws the petal module back, which simultaneously allows the refill piston to move forward, pushing fluid from the refill chamber into the delivery chamber. When the transfer solenoid is then released, allowing the inlet and refill valves to return to their original positions, more fluid will have been captured in the delivery chamber. Up to four such attempts are made to fill up the delivery chamber. If this does not fill the chamber, a "Solution" alarm is generated, otherwise, the system is checked for leaks.

After a pause the pressure is checked and if it has dropped too far, implying that the cassette or valves are not properly seated, an alarm is generated.

The restriction motor opens the restriction valve while the transducer signal is monitored. At the point where the valve starts to open, the pressure in the delivery chamber drops, and this is when actual pumping begins. The main motor steps forward at a constant speed determined by the selected delivery rate, and the pump processor monitors the transducer signal while controlling the restriction motor, so that the internal pressure is maintained at a constant level as determined by the selected maximum occlusion pressure. If the internal pressure rises, the restriction valve is opened, and if it drops, the valve is closed. This is necessary to insure accurate fluid delivery - if the pressure in the chamber is the same at the end of pumping as it was at the start, a predictable amount (approximately 0.83 milliliters) of fluid will have been delivered. Different control methods are used at different delivery rates, but the results are the same over the range of rates and pressures. Note that the pressure in the tubing will only be at the patient's pressure, plus any dynamic pressures in the tubing caused by the fluid flow itself or other items that may be obstructing the fluid flow.

At the end of the cycle, the restriction valve is closed to prepare for refill, and the transfer solenoid is actuated. Since the refill piston was pulled back as the main motor moved forward, the refill chamber has been filled from the I.V. fluid container. As the main motor is retracted and the piston returns forward, this fluid is pushed into the delivery chamber for the next cycle. The main motor is pulled back far enough that the piston travels fully forward.

Several checks are made during pumping to assure proper delivery. First, if the main motor encoder